

**Site 88 Building 25 Source Removal  
Non-Time Critical Removal Action Report  
Operable Unit No. 15**

**Marine Corps Base  
Camp Lejeune, North Carolina**

Prepared for



**Department of the Navy  
Atlantic Division  
Naval Facilities Engineering Command  
Norfolk, Virginia**

**Contract No. N62470-03-D-4401  
Task Order-030**

**August 2006**

Prepared by



# QC Review Page

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## Non-Time Critical Removal Acton Report

OU No. 15, Site 88

MCB Camp Lejeune

Jacksonville, North Carolina

Contract Task Order Number - 0030

Contract Number N62470-03-D-4401

AGVIQ-CH2M HILL JV 1 Program

*Prepared by*

AGVIQ

August 2006

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# Executive Summary

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Site 88 consists of former Building 25, the Base Dry Cleaning facility, and the surrounding paved and grassy areas. The site is located approximately 500 feet east of the intersection of Post Lane Road and McHugh Boulevard (formerly known as Main Service Road) in a developed area of MCB Camp Lejeune. Previous investigations indicated the presence of tetrachloroethene (PCE) and its daughter products in the lower portion of the surficial aquifer. In 1995, a "hot spot" of chlorinated solvents was identified during the removal of five underground storage tanks located on the north side of former Building 25. The contaminant plume extended northwest toward Building 43, at a depth of approximately 20 feet below ground surface. Subsequently, a Remedial Investigation and Supplemental Investigation were completed, followed by an Engineering Evaluation/Cost Estimate (EE/CA) in order to select a remediation technique to be used during this Non-Time Critical Removal Action. Shallow soil mixing of Zero Valent Iron (ZVI) and Clay was implemented for the purpose of remediating the source area.

The primary objective of the Non-Time Critical Removal Action was to implement Shallow Soil Mixing of Zero Valent Iron and Clay for treating the source area. The specific objectives for measuring the effectiveness of the removal were established as:

- Reduction in contaminant mass, as quantified by pre- and post-treatment groundwater data, soil data, soil vapor analysis, and membrane interface probe information.
- Minimization of contaminant mobility, as quantified by comparing groundwater data collected prior to and after the source area treatment.

Specific goals established for the removal action included:

- Remove/treat dense non-aqueous phase liquid (DNAPL) accumulations, to the extent practicable, from the identified source areas at Building 25.
- Reduce exposure and risk to human and ecological receptors.
- Reduce the potential for contaminant mass flux from the source zone to groundwater.

The Site 88 Non-Time Critical Removal Action began in September 2004. Colorado State University (CSU) conducted a treatability study to determine the optimum iron amount and effectiveness for the shallow soil mixing. From October 2004 through January 2005, site preparation activities took place at Site 88 including utility abandonment, monitoring well abandonment, demolition of the concrete foundation of former Building 25, and removal of several feet of soil. Shallow soil mixing began in February 2005, lasted 17 days and treated approximately 7,050 cubic yards of contaminated soil.

Groundwater monitoring, soil sampling, and soil gas sampling were conducted throughout the removal action. Post treatment monitoring took place from February 2005 to February 2006.



The removal action achieved greater than 90% reduction in PCE concentrations within the soil and groundwater; significant reduction in groundwater from downgradient monitoring wells; and 83% to 99% PCE reduction in soil gas. Groundwater samples from the treatment area had PCE below detection limits in one well and 91% reduction in the other. Additional work performed during the removal action results include:

- Hydraulic conductivity within the treatment area after treatment is 0.013 feet per day, compared to 4.1 feet per day before mixing.
- Stabilization of the treatment area was accomplished by adding 5% to 6% Portland cement to the unstable area and mixing with a backhoe.
- Site 88 now serves as a finished parking lot, with approximately 65 parking spaces including handicap access to Building 37.
- Water, steam, and electrical lines were installed to restore full operations to Buildings 37 and 43.



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# Acronyms and Abbreviations

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APAC	Ashland Paving and Construction, Inc
AST	Above ground Storage Tank
ASTM	American Society for Testing Materials
Baker	Baker Environmental, Inc.
bgs	below ground surface
<i>cis</i> -1,2-DCE	<i>cis</i> -1,2-Dichloroethene
cVOC	Chlorinated Volatile Organic Compound
CITT	Conservative Interwell Tracer Test
cm/s	centimeters per second
CPT	Cone Penetrometer Test
CSU	Colorado State University
cy	cubic yards
DCE	Dichloroethene
DNAPL	Dense Non-Aqueous Phase Liquid
DPT	Direct Push Technology
Duke	Duke Engineering and Services
DW	Deep Well
ECD	Electron Capture Detector
EE/CA	Engineering Evaluation/Cost Assessment
ERH	Electrical Resistance Heating
FID	Flame-Ionization Detector
ft	feet or foot
ft/day	feet per day
gpm	gallons per minute
GPS	Global Positioning System
HEPA	High Efficiency Particulate Air
IW	Intermediate Well
JV1	AGVIQ/CH2M HILL Joint Venture 1
lb	pound
LGAC	Liquid-Phase Granular Activated Carbon
µg/m <sup>3</sup>	micrograms per cubic meter
µg/L	micrograms per liter
µV	micro Volt
MCB	Marine Corps Base
mg/kg	milligram per kilogram
mg/L	milligrams per liter
MIP	Membrane Interface Probe

mL	milliliters
MP	Military Police
msl	mean sea level
MW	Monitoring Well
NAPL	Non-Aqueous Phase Liquid
NFESC	National Facilities Engineering Service Center
NTCRA	Non-Time Critical Removal Action
OHM	OHM Remediation Services Corporation
OU	Operable Unit
PCE	Tetrachloroethylene, perchloroethene, perchlorethylene, perc
PID	Photo-Ionization Detector
PITT	Partitioning Interwell Tracer Test
ppm	parts per million
PPE	Personal Protective Equipment
RAC	Remedial Action Contractor
RAOs	Remedial Action Objectives
RI	Remedial Investigation
rpm	revolutions per minute
SEAR	Surfactant Enhanced Aquifer Remediation
SOP	Standards of Practice
SSM	Shallow Soil Mixing
TCE	Trichloroethene
TCLP	Toxicity Characteristic Leaching Procedure
TPH	Total Petroleum Hydrocarbons
TW	Temporary Monitoring Wells
USDoD	United States Department of Defense
USTs	Underground Storage Tanks
VC	Vinyl Chloride
VOC	Volatile Organic Compound
Williams	Williams Environmental Services
ZVI	Zero Valent Iron

# 1. Introduction

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This Non-Time Critical Removal Action (NTCRA) report summarizes the field activities, data, results, and conclusions of source area treatment conducted at Operable Unit (OU) No. 15, Site 88, Marine Corps Base (MCB) Camp Lejeune, Jacksonville, North Carolina. The NTCRA was implemented by AGVIQ/CH2M HILL Joint Venture 1 (JV1). Shallow soil mixing (SSM) of Zero Valent Iron (ZVI) and Clay (ZVI-Clay) was implemented for the purpose of remediating groundwater impacted by chlorinated volatile organic compounds (cVOCs).

Site background information and the selection process for the NTCRA technology are presented in the following sections.

## 1.1 Site Description

MCB Camp Lejeune is located in Onslow County, North Carolina and covers approximately 236 square miles and includes 14 miles of coastline. The Base is bounded to the southeast by the Atlantic Ocean and to the northeast by State Route 24. The town of Jacksonville, North Carolina is located north of the Base (**Figure 1-1**).

Site 88 consists of the former Building 25, and the surrounding paved and grassy areas, and is located approximately 500 feet east of the intersection of Post Lane Road and McHugh Boulevard (formerly known as Main Service Road) (**Figure 1-2**). Site 88 is located in a developed area of MCB Camp Lejeune and is surrounded by buildings, parking lots, streets, and sidewalks. Buildings surrounding Building 25 include:

- The Counter Intelligence Office (Building 37) immediately to the north.
- Barracks to the east (Building HP57)/ a printing shop across Post Lane Road to the south (Building 80).
- A medical unit across Post Lane Road to the southwest (Building 4).
- Military Police (MP) Headquarters (Building 3) and a cobbler shop to the west (Building 43).

There is no surface water features located near former Building 25. Beaverdam Creek is the closest surface water, located approximately 1,500 ft. to the northeast, and the New River is approximately 3,000 ft. to the west.

### 1.1.1 Site History

Building 25 was used as a dry cleaning facility since the 1940's. Five underground storage tanks (USTs) were installed on the north side of the building to store dry cleaning fluids (**Table 1-1**). Initially, Varsol™ was used in dry cleaning operations at Building 25, although the use of Varsol™ was discontinued during the 1970's due to concerns about its flammability.



**TABLE 1-1**

Summary of Product Usage and Waste Disposal

*Operable Unit No. 15 – Building 25 Non-Time Critical Removal Action Report*

Product	Dates Used	Storage
Varsol™	1940's-1970's	Underground Storage Tanks
PCE	1970's- March, 1995	Above Ground Storage Tanks
PCE	March, 1995-Present	Self-contained dry cleaning units

Varsol™ was replaced by tetrachloroethene (synonyms: tetrachloroethylene, perchloroethene, perchloroethylene, perc, and PCE). The PCE was stored in one 150-gallon above ground storage tank (AST) adjacent to the north wall of Building 25, in the same vicinity as the USTs. PCE was reportedly stored in the AST from the 1970's until the mid-1980's. During this time, facility employees have reported that spent PCE was disposed of in floor drains. In March 1995, self-contained dry cleaning machines were installed in Building 25, eliminating the need for bulk storage of PCE, and the USTs and AST were removed.

### 1.1.2 Soil and Lithologic Information

A detailed discussion of the soil and lithologies at Building 25 is presented in the Focused Remedial Investigation (RI) Report (Baker, 1998) with additional information gathered during investigations performed in July 2002 and July through October 2003 by CH2M HILL.

The general profile of soils below Building 25 consists of alternating sands and silt turning into silty fine sands in the zone just above a low permeability silt and clay unit. Below the silt and clay low permeability unit, fine sands with varying amounts of clay and silt predominate. With increasing depth the sands contain less fines and display improved sorting. These partially cemented sands grade back to silty fine to medium sands. The treatment area is the alternating sands and silt with treatment stopping at the low permeability unit.

### 1.1.3 Geology and Hydrogeology

A detailed discussion of the geologic and hydrogeologic characteristics at Site 88 is presented in the Focused RI Report (Baker, 1998), the Surfactant Enhanced Aquifer Remediation (SEAR) Demonstration (Duke, 2000), and the Site 88 Source Removal Engineering Evaluation/Cost Assessment (EE/CA) (CH2M HILL, 2004). Information presented in this section summarizes those reports.

The hydrogeologic setting at Building 25 is that of two-aquifer system: the shallow aquifer and the Castle Hayne aquifer, with the two aquifers typically separated by a low permeability aquitard (Duke, 2000). This low permeability layer is present under Building 25 at approximately 20 feet (ft) below ground surface (bgs). This clayey-silt feature appears to decrease in thickness significantly to the northeast and again to the southwest.

During the October 2003 well gauging event, the upper surface of the unconfined surficial aquifer at Building 25 was found to occur at an elevation of 17.43 to 19.34 ft mean sea level

(msl) or 7.68 to 6.27 ft bgs. The static water level elevation within the upper Castle Hayne aquifer, during the October 2003 well gauging event, was found to range from 9.94 to 11.20 ft msl (above the base of the clay and silt low permeability confining unit) or 15.20 to 11.84 ft bgs. In general, groundwater flow is east to west across the source area, with components flowing to the southwest and northwest.

The water level elevation data depicts a significant difference in hydrostatic heads between the shallow and intermediate wells, with the higher heads being measured in the shallow wells. This suggests the potential for downward flow of water between the two well depths. However, the difference in heads also shows that the silt/clay layer is acting as an aquitard, inhibiting the flow of water or other fluids vertically downward.

## 1.2 Previous Investigations

The original investigation at Building 25 focused on the removal of five USTs, used to store dry cleaning fluids, located on the north side of Building 25. During removal of the tanks in November 1995 by OHM Remediation Services Corporation (OHM), soil and groundwater chlorinated solvent contamination was identified. Baker performed a Phase I RI in 1996. Based on the results of the Phase I RI, the Naval Facilities Engineering Service Center (NFESC) selected Building 25 as a candidate site to perform a SEAR demonstration. NFESC contracted Duke Engineering to conduct a dense non-aqueous phase liquid (DNAPL) investigation. The DNAPL investigation confirmed the presence of DNAPL at the site and characterized site conditions within the suspected DNAPL source area. Results of this DNAPL investigation were summarized within the DNAPL Site Characterization using Partitioning Interwell Tracer Tests (PITTs) (Duke, 1999).

Additional investigations include:

- Phase I and II Focused Remedial Investigation (Baker, 1997)
- DNAPL Site Characterization using Partitioning Interwell Tracer Tests (Duke, 1999)
- Supplemental Site Investigation - Baseline Groundwater Sampling (CH2M HILL, 2002)
- Supplemental Site Investigation (CH2M HILL, 2003)
- Membrane Interface Probe Investigation (CH2M HILL, 2004)

### 1.2.1 Focused RI - Phase I (April 1997)

A total of 38 temporary monitoring wells (TWs) were installed during Baker's April 1997 Phase I Investigation (Figure 1-3). Of the wells installed during this phase of investigation, 24 were shallow wells (15 to 20 ft bgs) and 14 were intermediate depth wells (approximately 50 ft bgs). These wells were used to characterize the nature and extent of contamination as well as provide information used to determine the placement of permanent wells. After the investigation was completed, all temporary wells were abandoned. The temporary well analytical results are summarized in Table 1-2.

### 1.2.2 Focused RI - Phase II (April/May 1997)

A total of 21 permanent groundwater monitoring wells were installed during Baker's Phase II study. Nine shallow wells were screened at the top of the surficial aquifer bracketing the water table (15 to 25 ft bgs). Eight intermediate depth wells (39 to 50 ft bgs; defined by the



"IW" suffix in the well identification) were screened at the top of the Castle Hayne aquifer, and four deep wells (85 to 97 ft. bgs; defined by the "DW" suffix in the well identification) were installed. The locations of these wells are shown in **Figure 1-3**.

Forty-one groundwater samples were collected from the temporary wells during the two phases of the RI. PCE was the most frequently detected compound in these wells (26 of 41 samples). TCE was detected in 19 of 41 samples. The maximum concentration observed in the temporary wells was PCE at 54,882 micrograms per liter ( $\mu\text{g/L}$ ) in IR88-TW22. The highest PCE concentration observed near the source area was 53,704  $\mu\text{g/L}$  in IR88-TW08.

### **1.2.3 DNAPL Site Characterization Using Partitioning Interwell Tracer Tests (Duke, 1999)**

The DNAPL source investigation was conducted in three phases. Phase I was performed July through August 1997. The objectives of the Phase I DNAPL source investigation were to locate the DNAPL zone and to perform the preliminary characterization of the hydrostratigraphy, the hydraulic and geochemical properties of the aquifer, as well as the approximate DNAPL saturations. These activities included soil sampling and detailed soil lithology data collection from eleven borings (IS01-IS11), followed by the installation of three wells (RW01, RW02, and IW01) to conduct hydraulic testing (**Figure 1-4**). Borings were completed beneath the building and around the building perimeter to a depth of about 21 feet bgs. Following development of the newly installed wells, free phase DNAPL was collected in RW01 and RW02. Soil analytical results confirmed the presence of residual PCE DNAPL at a depth interval of approximately 17 to 20 ft bgs.

A short-term pump test was conducted using well RW02, groundwater was extracted at a constant pumping rate of 0.5 gallons per minute (gpm). This hydraulic test revealed an average hydraulic conductivity value of 1.4 feet per day (ft/day) ( $5 \times 10^{-4}$  centimeters per second [ $\text{cm/sec}$ ]) and a specific yield of 0.01. These values were considered representative of the majority of the shallow aquifer in the SEAR demonstration area, however, field observation of core samples indicated the aquifer sediments became significantly finer (e.g. clayey silt) in the bottom 1 to 1.5 feet of the aquifer. This observation of lower hydraulic conductivity at the base of the shallow aquifer was confirmed by analysis of data from the PITT, which showed that the hydraulic conductivity was lower, by a factor of four.

The objectives of the Phase II DNAPL source investigation were to define the horizontal and vertical extent of DNAPL at Building 25, establish baseline DNAPL saturations in the SEAR demonstration area using soil borings, and to perform additional site characterization. Cone penetrometer tests (CPTs) were conducted at 12 locations around the periphery of Building 25 to map the upper and lower surfaces of the clay aquitard (**Figure 1-4**). Results of the CPT investigation indicated that the clay layer varies in thickness from about 8 to 14 feet thick on the north side of Building 25, 2 to 10 feet thick on the south side and about four inches near the southwest corner of the building.

Phase II also consisted of the completion of eighteen soil borings to delineate the horizontal extent of the DNAPL zone (**Figure 1-4**). The total depths of the soil borings ranged from 20 to 22 feet bgs and were generally terminated after penetrating the clay layer by about 1 to 2 feet. Soil samples were also analyzed to improve mapping of the depth to the upper surface of the clay layer, to determine the mineral content of the soil, and to analyze the fraction of sedimentary organic carbon in the soil samples. SEAR demonstration area wells and



associated recovery wells were installed during this phase of investigation (**Figure 1-4**). The analytical results from soil (**Table 1-3**) and groundwater samples (**Table 1-4**) collected during the investigations were analyzed using NAPLANAL, a computer code developed by Duke (Mariner et. Al, 1997). The NAPLANAL analysis indicates that DNAPL was present directly underneath Building 25 and in an area adjacent to the north side of the building. The DNAPL saturation generally increased in depth from about 16 to 20 feet bgs.

Phase III of the DNAPL investigation included field implementation of the pre-SEAR PITT, as well as preparatory field activities. The PITT involved the injection of a suite of tracers in the injection wells and the subsequent extraction from the extraction wells. Analyses of the test results allowed the detection and estimation of the DNAPL volume present in the aquifer between the injection and extraction wells before the implementation of the SEAR pilot study. Free phase DNAPL recovery was performed before the initiation of the pre-SEAR PITT. Approximately 30 to 60 gallons of free phase DNAPL was removed from the subsurface during the free phase DNAPL recovery effort.

A conservative interwell tracer test (CITT) was conducted first to evaluate the preliminary PITT design. The pre-SEAR PITT was conducted for 40 days in 1998. Data analysis estimated that 74 to 88 gallons of DNAPL was present in the SEAR demonstration area. Percent DNAPL saturations were estimated under the assumption that the fraction of pore space occupied by the DNAPL, as calculated by NAPLANAL, is equal to the DNAPL saturation. Average DNAPL saturations in the test zone were found highest in the area adjacent to the north wall of Building 25, at approximately 4% saturation. The DNAPL saturation appeared to decrease to about 0.4% saturation at a distance of approximately 20 feet north of the building. However, results of soil column studies conducted prior to the PITT suggested that this low level DNAPL saturation (0.4%) is actually the result of tracer sorption to sedimentary organic matter that is observable as peat particles in the sediments. Therefore, the report stated that the area of the SEAR demonstration zone 20 feet north of the building is believed to be DNAPL free.

### **1.3 Supplemental Investigations**

In order to gain a better understanding of the conditions at the site and to evaluate the remedial alternatives, supplemental investigations were performed. Groundwater sampling, a sewer survey, soil sampling to characterize lithology, aquifer testing, gamma logging, groundwater sampling using direct push technology, and membrane interface probe (MIP) investigation were all used to characterize the site and source area.

#### **1.3.1 Supplemental Site Investigation – Baseline Groundwater Sampling (CH2M HILL, 2002)**

In July 2002, CH2M HILL collected groundwater samples from 22 site wells. The wells were tested for volatile organic compounds (VOCs), total metals, and natural attenuation parameters such as sulfate. The major contaminants of concern were several VOCs including: PCE, trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride (VC). Results indicated significant groundwater contamination at Building 25. These results are discussed further in Section 8.3.1



### 1.3.2 Supplemental Site Investigation (CH2M HILL, 2003)

Several site investigation activities were performed during July 2003 through October 2003 to address the data gaps needed to complete the comprehensive RI for Site 88. These activities consisted of monitoring well installation, a sewer survey, soil sampling to characterize lithology, aquifer testing, gamma logging, groundwater sampling using direct push technology, and monitoring well sampling. The locations of these wells are shown in Figure 1-3.

In July 2003, CH2M HILL performed a sewer survey using cameras to identify areas of significant compromising of joint integrity and areas of significant separation in the sewer line (Figure 1-5). These areas are potential DNAPL migration pathways.

The results of the October 2003 groundwater monitoring event are discussed in Section 8.2.3.

The vertical distribution of VOCs suggests that although appreciable volumes of DNAPL are observed to accumulate upon the shallow clayey-silt layer, this layer is either not impermeable or continuous, and is evidently allowing dissolved-phase VOCs to migrate vertically to the intermediate depth wells.

### 1.3.3 Membrane Interface Probe Investigation (CH2M HILL, 2004)

A membrane interface probe operated by Vironex was used to refine previous source area characterization efforts and conduct vertical soil profiling in the vicinity of Building 25 and the sewer systems nearby (Figure 1-6). The MIP system utilized during this investigation was equipped with three detectors: photo-ionization detector (PID), flame-ionization detector (FID), and electron capture detector (ECD). Detector response to sorbed, dissolved, or free phase contaminants varies spatially due to changes in soil type and weathering state of the contaminant. Generally, the MIP provides high-resolution (typically in increments of less than 0.5 feet) VOC profiles for soil and groundwater within the reach of direct push technology (DPT) equipment. The MIP detectors do not provide definitive quantitative data, but rather semi-quantitative information that permits the user to identify centers of mass and concentration gradients.

In order to evaluate the presence of free product (accumulating upon the clayey silt layer previously encountered at 18 to 22 feet below ground surface), or DNAPL, each MIP boring was advanced until the soil conductivity probe indicated a lithologic transition. A baseline MIP detector response to the chlorinated solvents present at Site 88 was acquired from MIP boring 88-MIP-(B2), advanced in an area known to contain an accumulation of 0.8 feet of DNAPL. A total of 58 MIP borings were completed at Site 88.

Since the dry cleaning solvents released around Building 25 are predominantly chlorinated hydrocarbons, the primary MIP response was observed on the ECD. The maximum range of the ECD detector was frequently exceeded. Elevated PID responses and to a lesser degree FID responses were also observed in areas known to contain non-aqueous phase liquid (NAPL). For this reason, the PID and FID responses were used in concert with the ECD to evaluate the presence of heavily impacted soil and groundwater.

As previously stated, the initial MIP borings were advanced in areas of known free product accumulations. The detector responses from these borings indicated that ECD, PID and FID



responses of greater than approximately  $1.2 \times 10^6$  micro Volts ( $\mu\text{V}$ ),  $1.0 \times 10^6$   $\mu\text{V}$ , and  $4.5 \times 10^5$   $\mu\text{V}$ , respectively, likely indicated the presence of free product. Also, in areas of known free product accumulation, the form of the detector response was often seen to be 'flat-topped' (i.e., sufficient contaminant mass was encountered to maintain a constant detector response).

The information provided by the MIP investigation was used to generate **Figure 1-7**, which illustrates the estimated horizontal extent of the source area, i.e. the area of ECD responses exceeding  $1.0 \times 10^6$   $\mu\text{V}$  and PID responses greater than 100,000  $\mu\text{V}$ . **Figure 1-8** displays the orientation of the cross section shown by **Figure 1-9**. **Figure 1-10** presents the vertical distribution of VOCs (as detected by the MIP PID) along the B-B' cross section. **Figures 1-11, 1-12, and 1-13** display the MIP PID response at 10 feet bgs, 15 feet bgs, and 20 feet bgs, respectively. The vertical distribution of DNAPL in the source area is presented on **Figure 1-14**.

Groundwater samples from SEAR wells RW02 and EX04 were obtained during the MIP investigation. Detections from these samples indicate high concentrations of PCE, TCE, 1,2-DCE, and VC are still present in the SEAR demonstration area. The analytical results are discussed further in Section 8.4.1.

## 1.4 Previous Removal Actions

### 1.4.1 Previous Pilot Study - Surfactant Enhanced Aquifer Remediation

In 1999, Duke in cooperation with Baker, completed a focused demonstration of SEAR at Building 25. The demonstration involved the injection and subsequent extraction of a surfactant solution from a treatment cell measuring approximately 20 feet by 30 feet, located on the north side of Building 25 (United States Department of Defense [USDoD], 2001). **Figure 1-4** shows the location of the SEAR wells and soil sample locations. All wells were installed within the surficial aquifer, to a depth of approximately 20 ft bgs.

As part of the SEAR demonstration, Duke performed a pre-PITT and a post-PITT in 1999 to quantify the DNAPL contamination present both before and after the surfactant flood. However, the results of the post-SEAR PITT proved to be unusable due to the interference by a sorbed fraction of the surfactant that remained in the aquifer. The post-SEAR PCE concentrations are shown in **Table 1-5**.

SEAR activities revealed that the zone around Building 25 can be divided into roughly three permeability zones: the upper zone from approximately 16-17.5 ft bgs, the middle zone from approximately 17.5-19 ft bgs, and the lower zone at approximately 19-20 ft bgs. The hydraulic conductivity in this upper zone is estimated to be about 1.4 ft/day. The hydraulic conductivity of the middle zone is estimated to be approximately 0.28 ft/day. The lower zone is predominantly composed of clayey-silt with a hydraulic conductivity believed to be 0.14 to 0.03 ft/day.

Continuous surfactant injection was performed beginning on March 15, 1999, and ending on August 30, 1999. The pre-SEAR PITT estimated the total volume of the DNAPL present in the test zone was 74-88 gallons. However, based on the volume estimated by the pre-SEAR PITT and the soil core data, the total pre-SEAR DNAPL volume is believed to have been



approximately 105 gallons. A post-SEAR investigation estimated the volume of DNAPL remaining in the treatment cell to be approximately 29 gallons (Duke, 1999).

Groundwater PCE concentrations remaining at the end of the SEAR test in August 1999 ranged from 9.6 to 164.1 mg/L. The highest concentration was found in RW06.

#### 1.4.2 DNAPL Recovery

In February 1998, a DNAPL recovery system was installed to remove as much DNAPL as possible from the SEAR test zone. Wells EX01, IN01, HC01, RW01, RW04, and RW06 were used as DNAPL recovery wells (Figure 1-4). The DNAPL recovery process was conducted in two stages. The first stage involved preliminary pumping of DNAPL that had accumulated in the recovery wells with a peristaltic pump. The second stage consisted of pumping the six DNAPL recovery wells simultaneously to create a hydraulic gradient. The combined total flow from all six recovery wells during the recovery operation was approximately 1.3 gpm. The pumped fluids were composed primarily of contaminated groundwater with a much smaller component of DNAPL. Attempts to quantify the volume of recovered DNAPL were generally unsuccessful. This DNAPL recovery was terminated in March 1998.

Free-phase DNAPL recovery activities continued during the simultaneous injection and extraction operations of the CITT for 14 days and the PITT for 40 days. Pumping was from the six extraction wells EX01-EX06 with no pumping from RW04 or RW06.

It is estimated that the total amount of DNAPL recovered during these activities is probably about 30 to 60 gallons. The DNAPL Site Characterization Using PITTs (Duke, 1999) stated that the low permeability of the shallow aquifer greatly limited the rate at which free-phase DNAPL was recovered.

The shallow monitoring wells and former SEAR wells adjacent to Building 25 were gauged weekly to monitor the accumulation of DNAPL. When detected, the Base Remedial Action Contractor (RAC) removes the DNAPL by vacuum extraction.

## 2. Source Removal Area

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### 2.1 Area Dimensions

The estimated source zone is based primarily on the 2004 MIP investigation, soil sampling, and groundwater sampling. The source area around Building 25 is approximately 10,000 square feet with treatment volume of approximately 7,000 cubic yards (cy). The depth of contamination extends into the silty clay layer for a total depth of approximately 20 ft bgs. The 7,000 cy of treatment volume includes approximately 1,000 cy of vadose contamination (located beneath and around Building 25). Figure 8-1 shows the approximate treatment area.

### 2.2 Estimated Contaminant Mass

Estimating the contaminant mass in the treatment area is difficult. The primary driver for contaminant mass is the amount of product in the subsurface. DNAPL is not a continuous layer in the subsurface, but is probably located in pockets and ganglia.

Using the Colorado State University (CSU) baseline analytical data, an assumed soil density and the treatment area volume, an estimate of contaminant mass can be calculated (Appendix A). With an average PCE concentration within the soil of 1,097 mg/kg, a treatment area volume of 7,000 cy and soil density of 1.5 tons/cu yd., the estimated contaminant mass within the treatment area is approximately 23,000 lbs. This estimate is probably low considering that the samples were not preserved and some samples were broken upon arrival to CSU, leading to contaminant loss and a lower contaminant mass. However, the samples were collected immediately following soil mixing.

### 2.3 Engineering Evaluation/Cost Analysis (CH2M HILL, 2004)

The purpose of the EE/CA was to analyze removal or treatment action alternatives for contaminant mass removal or treatment at the identified source areas around Building 25. The remedial alternatives evaluated in the EE/CA were intended to address the identified source area only. The actions are intended to remove or treat, as much DNAPL from the source area as is practical and cost effective. Other remedial action objectives (RAOs) are to reduce exposure and risk to human and ecological receptors, and to reduce the potential for contaminant mass flux from the source zone to groundwater. Four alternatives were evaluated to remediate the DNAPL impacted area: excavation of contaminated soil, electrical resistive heating (ERH), pneumatic fracturing and dual phase extraction followed by reductive dechlorination, and shallow soil mixing. Based on the effectiveness, implementability, and cost, shallow soil mixing with a ZVI-Clay slurry addition is the recommended remedial technology for the DNAPL source area located around Building 25.

### 3. Project Chronology

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The Site 88 NTCRA and associated field activities were conducted between September 2004 and March 2006. A chronology of the NTCRA is presented in **Table 3-1**.

**TABLE 3-1**  
NTCRA Chronology  
*Operable Unit No. 15 – Building 25 Non-Time Critical Removal Action Report*

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September 2004	Treatability Study
October 2004 to January 2005	Utility Relocation and/or Abandonment, Monitoring Well Abandonment
November 2004 to January 2005	Demolition of Concrete Pad
January 2005	Soil Debris and Removal
February 2005	Soil Mixing
April 2005 to July 2005	Stabilization
August to September 2005	Parking Lot Construction
February 2005 to March 2006	Post Treatment Monitoring

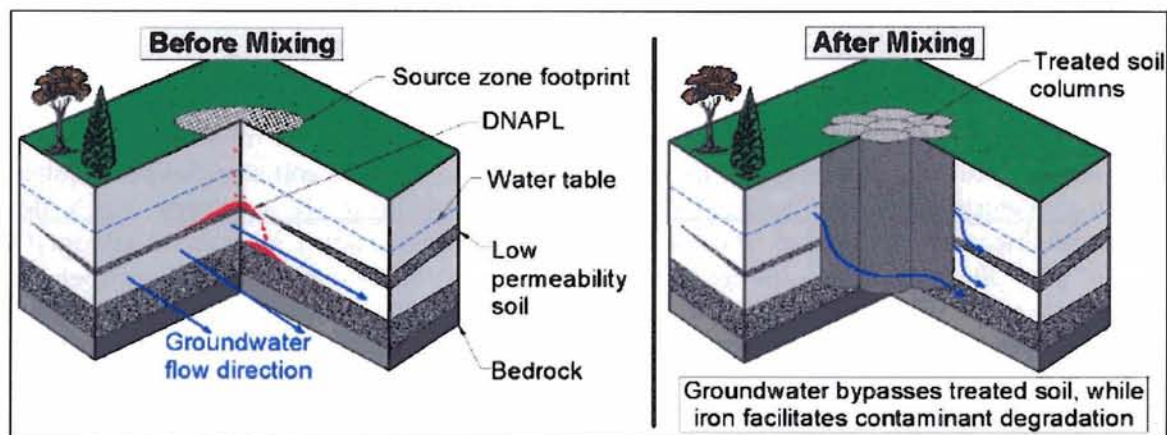
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## 4. Implementation

### 4.1 Technology Description

Shallow soil mixing is an in-situ technology that uses a large auger system with the ability to deliver zero-valent iron and clay (ZVI-Clay) slurry into the soil while mechanically breaking up and mixing the soil. Shallow soil mixing distributes the DNAPL source zone into a homogenous mixture of soil, clay, iron, and target contaminants by turning a large diameter auger while cycling up and down throughout the mixing column. ZVI is a strong reducing agent and its properties are well suited to the treatment of many common dissolved contaminants. The clay promotes uniform distribution of the iron during the mixing process. It will also reduce the hydraulic conductivity of the source zone, so that contaminant mobility is reduced.



ZVI is a strong reducing agent and its properties are well suited to the treatment of many common dissolved contaminants. Under certain groundwater conditions, elemental iron is slowly oxidized to ferrous iron, releasing two electrons in the process. These electrons participate in a variety of reactions leading to the transformation of the target contaminant.

The reaction proceeds through two known pathways. In the beta-elimination pathway, the formation of partially dechlorinated products such as dichloroethene (DCE) and VC is avoided, and PCE and TCE are transformed directly to ethene via the production of some short-lived intermediates, such as chloroacetylene and acetylene. Most experts believe that chlorinated solvents degrade primarily through the beta-elimination pathway when exposed to iron. Very little DCE or VC have been found in laboratory or field studies with iron, indicating the dominant mechanism is probably beta-elimination. In the

hydrogenolysis, or sequential degradation pathway, one chlorine atom is removed in each step, so that TCE degrades to *cis*-1,2 DCE, then to VC, and finally to ethene and ethane.<sup>1</sup>

Slurry injection and mixing can create a fluff or increase in soil volume. The amount of resulting fluff is a function of the soil type, injection volume, reagent type, and operating conditions. To contain this fluff, roughly 1,000 cy of soil would be removed prior to mixing for disposed at the Base landfill. Subsurface utilities in the treatment area would be removed at this time as well.

Fugitive emissions may occur during the addition of the ZVI-Clay slurry. These emissions will be captured from the mixing zone by a removable hood. The removable hood is an open bottom cylinder that covers the surface of the mixing zone while mixing is preformed directly beneath. Negative pressure is kept on the headspace of the hood, pulling any vapors and dust to a vapor treatment system. When mixing is completed, the blades of the mixing auger are retracted inside the hood and the unit is moved to the next location.

## 4.2 Treatability Study

CSU conducted laboratory studies that characterize the potential to treat PCE and associated degradation intermediates using ZVI-clay. Results indicated that the target compounds could be degraded and provided a basis for resolving some aspects of field implementation.

As a first step, 153 soil cores from eleven locations and three 40 milliliter (mL) vials of DNAPL were collected from the treatment area at Site 88. The soil samples were collected using a Geoprobe at a depth of 14 to 22 ft bgs on a grid pattern. The soil cores were sealed in acetate liners and shipped to CSU for inclusion in laboratory studies. Soils were logged and split into six composite samples, including samples for 1) composite soil properties, 2) analysis of the efficacy of ZVI-Clay treatment, 3) mixed DNAPL distribution studies, 4) hot air flushing studies, 5) post mix studies, and 6) archiving. Contaminants observed in the composite samples (post sample handling) include PCE (maximum of 5 milligram per kilogram [mg/kg]) and trace levels of TCE and DCE. The soils consist of varying combinations of fine sand, silt, and clay.

The studies to evaluate ZVI-clay efficacy for treatment of PCE (and associated compounds) involved two components: unspiked soil and DNAPL spiked soils. The experimental setup for the unspiked soils involved 1) admixing varying amounts and types of iron with bentonite clay and soils collected from Site 88 and 2) measuring concentrations of target compounds at 3, 7, 14, 31 and 59 days. The spiked soil study involved addition of DNAPL (collected from Site 88), admixing varying amounts and types of iron with bentonite clay and the spiked soils, and measuring concentrations of target compounds at 3, 7, 14, 31 and 59 days.

Results of the treatability study indicated an approximate 75% decrease in PCE over the 59-day study. Extrapolating the observed degradation rates through time, it appears that the vast majority of PCE can be depleted in a period of a year or less. Also, significant accumulation of TCE, DCE isomers, or VC was not observed.

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<sup>1</sup> Environmental Restoration Technology Transfer (ERT2) Webpage  
<http://www.ert2.org/ert2portal/DesktopDefault.aspx>



Studies with 1, 3, 5 and 7 % Peerless™ iron (dry soil weight basis) indicated faster rates of degradation with greater amounts of iron. However, similar overall decreases were observed after 59 days. Assuming reaction rates remain constant, and considering periods of a year or more, a similar endpoint could be achieved with any of the iron treatments. The only difference might be how quickly the endpoint is reached. The optimum mixing blend to be injected into the DNAPL source area was a grout containing 2% ZVI-clay and 1% bentonite.

DNAPL spiked studies indicated slightly lower rates of removal and lower reaction rate constants compared to the unspiked study. Half-life estimates are approximately 30 days for the DNAPL spiked soil compared to approximately 20 days in the unspiked soils.

In addition, two column mix studies were conducted. In the first, pure PCE was injected into the midpoint of three soil columns. Simultaneous mixing and injection of ZVI-Clay dispersed the DNAPL without affecting apparent adverse downward DNAPL migration. In the second set of column studies, addition of ZVI-Clay with and without hot air injection was compared. No significant improvement in performance was observed with hot air injection. Analysis of soils from both sets of column studies verifies the apparent rate of PCE treatment seen in the ZVI-Clay efficacy studies. Observed expansion of soil through treatment in these studies was 12-15%. Theoretical calculation using conservative assumptions indicates expansion could be 25%.

A copy of the treatability study report is located in (Appendix B).



## 5. Site Preparation

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### 5.1 Utility Removal / Abandonment

All utilities located within the treatment area were rerouted or abandoned. The utilities rerouted include: water, electric, and steam (**Figure 5-1 and 5-2**). The sanitary sewer line does not pass through the treatment area and was not abandoned. Building 37 was previously supplied with steam through a line from the steam vault on the north side of Building 25. This steam pit was removed since it was within the treatment area.

- Water Line: Approximately 220 ft of water line going to Building 25 and Building 43 to the water main were removed.
- Electric Lines: Approximately 285 ft of overhead electrical lines had to be disconnected and removed.

Utilities no longer servicing the area after the removal action include the steam/condensate lines and the storm sewer.

- Steam/Condensate Lines: 215 ft – The steam/condensate lines that run from the steam vault to buildings 43 and 37 were removed.
- Storm Sewer: 100 ft – The storm line to the north west of 37 was removed and plugged.

### 5.2 Monitoring Well Abandonment

In order to prepare the source area for treatment, the groundwater monitoring wells within the treatment area were abandoned. There were 19 wells within the treatment area to be abandoned including monitoring wells, extraction wells, recovery wells, injection wells, and hydraulic control wells (**Figure 5-3**). The majority of the wells, 13 of 19, were abandoned in early October. During the abandonment of EX01, high vapor readings on the FID were experienced and the action level for an upgrade in personal protective equipment (PPE) was reached. Work was stopped until appropriate health and safety procedures could be implemented. The remaining treatment area wells were abandoned by a subcontractor during the first week of January 2005.

### 5.3 Soil and Debris Removal and Disposal

The concrete slab remaining from the demolition of Building 25 was broken up and disposed of at the Base recycling area. Clean fill material was excavated from the treatment area to account for the fluff of soil mixing and was disposed of. Approximately 10-20% of the treatment area was removed to account for the volume increase due to fluff. The area of excavation was extended outward laterally from the treatment area boundary in order to keep the excavation area to a depth of 3 ft or less. The soil was screened with a PID air monitoring device during the excavation. If screening indicated potential VOCs, the soil was

not removed, but moved within the treatment area. Approximately 1,600 tons of soil and debris were disposed of at the Base landfill during January 2005,

In order to insure that the Base landfill could dispose of the excavated soil, a representative sample was analyzed, and the results provided to the Base landfill. A soil sample was collected from approximately one ft bgs during the treatability sampling event. The sample was analyzed for VOC, toxicity characteristic leaching procedure (TCLP), and total petroleum hydrocarbons (TPH). An additional two surface soil samples were collected for TPH analysis. These sample results were submitted to the Base landfill contact to confirm that the excavated soil may be disposed at the base landfill.

Any rebar of reinforcement protruding from concrete was cut flush. Debris was segregated according to material type (e.g., concrete, metal, and plastic, etc). The concrete went to the concrete debris area and the steel rebar was removed off-site to a local facility for recycling. Asphalt material was taken by truckload to a local asphalt recycling facility.



## 6. Soil Mixing

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Soil mixing activities were conducted from February 11, 2005, until February 28, 2005 by Williams Environmental Services' (Williams). A 10 ft. diameter auger was used to mix the soil with the ZVI and clay. A batch plant was constructed on site to prepare the iron-bentonite slurry mixture to the project specifications.

### 6.1 Shallow Soil Mixing Treatment

Shallow soil mixing was performed using a 10-foot diameter auger, constructing an approximate total of 146 soil mixing columns. A 150-ton Manitowoc 4000 W series crane, and a 300,000 foot-pound rotary torque drill rig were used to mix the soil. The ZVI-clay slurry was pumped through the hollow Kelly Bar, which is connected to the auger (**Figure 6-1**). The auger was equipped with injection ports to inject the slurry into the soil. As the auger rotates, the slurry is pumped and mixed with the in-situ soils. The auger's continued rotation and downward movement provide homogeneously-mixed columns to the desired depth. The mixing shaft speed was adjusted to accommodate a constant rate of mixing and shaft penetration based on the degree of drilling difficulty, shaft speed ranged from 0 to 20 revolutions per minute (rpm). The penetration rate was modified during mixing activities to account for proper mixing and production rates, the penetration rates ranged from one to four vertical feet per minute.

The centers of the columns were positioned in the treatment area so the columns overlapped to treat 100% of the area. The center points of each column were laid out each day prior to drilling using a sub-meter accurate Global Positioning System (GPS) unit. During soil mixing activities, 146 columns were advanced to 20 ft. and approximately 7050 cy of impacted soil was treated (**Figure 6-2**). The column mixing depth was determined by painting a depth indicator mark on the Kelly bar. When the Kelly bar was submerged, and the indicator mark no longer visible, the mixing auger had been advanced to the desired depth, in this case 20 ft bgs.

The slurry was injected through the augers as the augers rotated and mixed with the soil. The slurry was produced in Williams' high-shear mix plant, capable of producing up to 1,000 gallons of ZVI-clay per batch. The soil mixing process consisted of four batches. Batches one, two, and three, consisted of three 100-pound (lb) bags of bentonite and 400 gallons of water each. Batch four consisted of one 100-lb bag of bentonite and one supersack of either 2,500 lbs or 2,230 lbs of iron filings, each column was mixed a minimum of six times. For each 10 ft diameter column, Williams blended approximately 124 lbs of iron and 62 lbs of bentonite with soil per vertical foot. This achieved the specified 2% iron and 1% bentonite addition to the soil by weight.

### 6.2 Mixing Quality Control

In order to evaluate the mixing of the iron-clay slurry throughout the columns, Williams conducted slurry mixture sampling and testing. Samples were collected each day at depths



of 5 ft and 15 ft Williams' wet sampling tool was lifted with an excavator and inserted into freshly mixed columns to the desired depth. Approximately 100 grams of the composite sample was used in the magnetic separation testing. The dry unit weight was determined for each sample. Each sample was washed several times to remove fine materials. A magnet was used to separate the iron from the mixture while the mixture was wet. The separate iron was then dried and a magnet was used again to separate iron filings from the remaining native material in the mixture. Williams' Site 88 Source Removal through Soil Mixing Summary Report and Magnetic Separation Sampling Test Results are located in (Appendix C).

### **6.3 VOC Off-Gas Treatment**

Williams installed a soil vapor extraction system onsite to capture volatilized contaminants that escaped through emissions during the mixing around the auger. The system consisted of a 14 ft diameter shroud that covered the area of the mixing column. Negative pressure was kept on the headspace of the hood using a 1,800 cubic feet per meter variable speed vacuum unit, pulling any vapors and dust to a vapor treatment system. Components of the vapor treatment system include a high efficiency particulate air (HEPA) filter for dust particle removal, a 3,000 lb. granular activated carbon filter and a discharge stack (Figure 6-3).

Williams monitored off-gas during drilling activities using a PID to ensure that carbon breakthrough did not occur. Monitoring was performed each day of drilling every two hours at the intake of the carbon container and at the discharge stack. No readings were recorded over 0 parts per million (ppm.) from the discharge stack. The maximum PID reading for the influent to the carbon unit was 539 ppm.

## 7. Site Restoration

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### 7.1 Utility Installation

In order to restore the site back to working condition, water, steam, and electrical lines had to be installed to Buildings 37 and 43. The following is a list of the utilities installed in and around the treatment area.

- Water Line: 130 ft. of new water line was required to service Building 43.
- Steam/Condensate Line: A new steam line of 230 ft was installed from an existing steam vault near Post Lane Road, running along the west side of the treatment area to Building 37.
- Electrical Line: 300 ft of overhead lines were needed to reroute electrical power out of the treatment area.

### 7.2 Stabilization

Upon completion of the shallow soil mixing activities, stabilization of the soil was required in order to proceed with construction of the parking lot. Stabilization activities took place from April 25 through the end of May 2005. Stabilization was performed by mixing cement into the top 5 to 10 feet of the treatment area.

After mixing, soil samples from within the treatment area underwent geotechnical testing. Samples were tested for moisture content (American Society for Testing Materials [ASTM] D2216), undrained shear strength (ASTM D4648), and uniaxial consolidation (ASTM D2435). A solidification study was performed by mixing the treated soil with various concentrations of Portland cement and then testing for unconfined compression strength (ASTM D2166) at 7, 14, and 28 days. The strength stabilization results (**Appendix D**) were then used to determine the amount of cement approximately one month after the soil mixing operation is complete.

The treatment area was stabilized using the predetermined 5% Portland cement mix ratio, and mixed to 5 ft bgs. Mixing was conducted by adding one ton of cement to a 10 ft. by 10 ft. area, over the entire treatment area. After stabilization, a significant portion of the treatment area was stable with this cement ratio and at this depth, while the center of the treatment area was still soft. The center of the treatment area was then divided into a grid pattern, with twenty eight 15 ft. by 15 ft. grids. Each grid was then stabilized to 10 ft bgs with 6% Portland cement. In total, 190 tons of cement was used to stabilize the treatment area. A series of quality control tests were then used to assure stabilization. The results of the quality control tests including cone penetrometer results, proof rolling results, and locations of ponded water are included in **Appendix E**.



### 7.3 Parking Lot Construction

After completion of the soil mixing and site stabilization, a parking lot was constructed over the site during September 2005. The design was coordinated with Base Facilities and Ashland Paving And Construction, Inc. (APAC.) The cross section of the parking lot consists of multiple layers. The prepared base layer or subgrade consists of 12 inches of local soil or fill, followed by a layer of geotextile fabric, then a 6 inch layer of crushed stone, an 8 inch layer of graded aggregate, and the final layer is 2½ inches of asphaltic concrete surface. Quality control measures taken include subgrade compaction measurement and aggregate compaction to standard proctor density in order to insure maximum load capacity of parking lot. Pentrometer testing was also used for quality control to insure proper density of surface layer.

Approximately 38,000 square feet was paved for the parking lot, requiring approximately 1,450 tons of asphalt. The lot includes 65 parking spaces, including handicap spaces, with access to Building 37. Other improvements include stormwater drainage, with approximately 400 ft of drainage pipe installed including necessary manholes and junction boxes, parking lot markings, bumpers, etc. The as-built drawings and details are show in (Appendix F).

### 7.4 Monitoring Well Installation

As part of the treatment area restoration and continued monitoring of the remedial activities performed by SSM, four monitoring wells were installed within the treatment area between October and November 2005 (Figure 1-2). The purposes of these wells are to monitor any contaminant migration from the treatment zone, both horizontally and vertically. Monitoring wells installed include: MW-30, MW-30IW, MW-31, and MW-31IW. Both intermediate monitoring wells are Type III monitoring wells, which are double cased in order to prevent downward migration. All wells installed have a flush mount finished appearance, with the shallow wells having a total depth of 20 ft bgs and the intermediate wells have a total depth of 40 ft bgs. The shallow wells are screened from 3 to 18 ft bgs and the intermediate wells from 35 to 40 ft. bgs. All four wells have a 2 inch casing diameter.

## 8. Monitoring

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The performance of the NTCRA was measured through monitoring of soil gas, soil, groundwater sampling and analysis and comparing MIP data. Baseline and historic data was compared to data collected after soil mixing.

### 8.1 Soil Gas Sampling

#### 8.1.1 Baseline Soil Gas Data

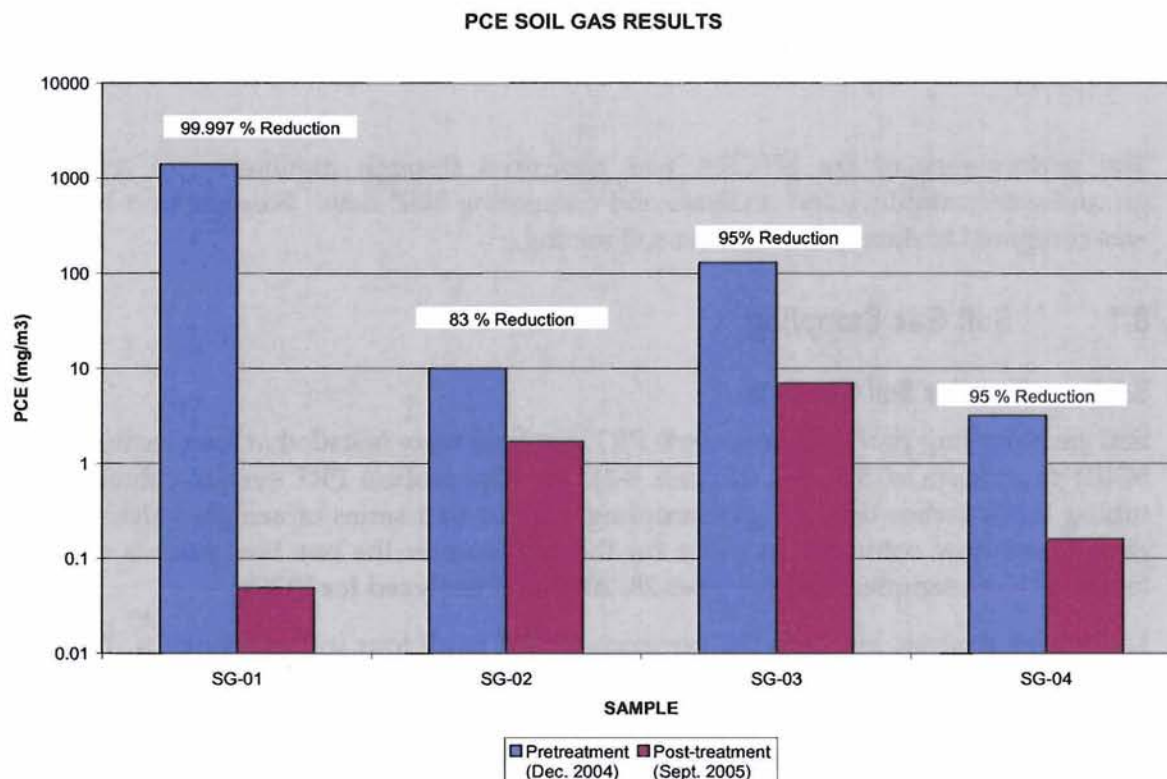
Soil gas sampling probes (Geoprobe® PRT systems) were installed at four locations (SG01 – SG04) to a depth of 5 ft bgs, (**Figure 8-1**). The Geoprobe® PRT system contains Teflon® tubing that attaches the PRT gas sampling adapter to a series of sample valves, a vacuum gauge, and flow controller in order for the gas to enter the one liter summa canister. All locations were sampled on December 28, 2004, and analyzed for VOCs.

Laboratory analysis indicates the presence of PCE in all four soil gas samples, TCE and VC in three of four samples. The highest levels of concentration of PCE and TCE occurred in SG01, at 1,400,000 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) and 4,500  $\mu\text{g}/\text{m}^3$ , respectively. The highest concentration of VC occurred in SG02 at 57,000  $\mu\text{g}/\text{m}^3$  (**Table 8-1**).

#### 8.1.2 Post Treatment Soil Gas Data

Four soil gas samples were collected after the parking lot was constructed from similar areas as the pre-treatment samples and analyzed for VOCs (**Figure 8-1**). Soil gas sampling was conducted on September 29, 2005 in order to compare results to the previous soil gas sampling event during late December 2004. This was approximately seven months after treatment. Analytical results (**Table 8-1**) indicate significant reduction in VOC concentrations in three of the four soil gas locations. Sample locations SG01 and SG02 had the most significant reductions. PCE and TCE concentrations were reduced by 99.97 percent and greater than 98 percent respectively at SG01. While PCE, *cis*-1,2-DCE, and VC were reduced by 83 percent, 87.5 percent, and 99.5 percent respectively at SG02. At SG03, PCE was reduced by more than 89 percent, but *cis*-1,2-DCE, VC, and 2-Propanol all increased. However, SG03 was located just outside the treatment area. At SG04, PCE was reduced by 95 percent, while VC, and *cis*-1,2-DCE both increased. These increases could be due to degradation of the parent contaminant, PCE.





## 8.2 Soil Sampling

### 8.2.1 Baseline Soil Data

The original intent of baseline soil sample collection was to collect discrete soil samples using a Geoprobe®. However, in reviewing the soil results, they were not indicative of observed product, groundwater sampling results, and MIP investigation results. Because of this disparity, other data is used for the baseline (pretreatment concentrations), include the post-SEAR test data and data analyzed by CSU.

CSU requested samples from the treatment area immediately after mixing, but this was not in the original work plan. Therefore, sample collection during February 2005 was not in accordance with CH2M HILL Standards of Practice (SOP). However, upon reflection, these samples taken from the treatment area are truly representative of baseline conditions, which is why they are presented.

Twenty confirmatory soil samples were collected by CH2M HILL within ten different mixing columns in the treatment area and analyzed by CSU for a treatability study. The samples were taken the day of or the day after mixing. The samples were not collected in accordance with CH2M HILL protocol and were left unpreserved and some were damaged or broken upon arrival at CSU for analysis. Therefore, the actual concentrations are likely to be higher than they appear for the February 2005 sampling event. Table 8-2 contains the data from the individual columns.

During the post-SEAR sampling event, samples were collected from 17.0 to 20.0 ft bgs at six inch intervals. Post-SEAR sampling results indicate the highest concentrations of PCE are located between 18.5 and 19.5 ft bgs. The average PCE concentration for all samples collected in the sampling area is 3,352 mg/kg. Within the sample area, concentrations were lowest from 17.0 to 17.5 ft bgs with an average concentration of 350 mg/kg. Concentrations were at a maximum from 18.5 to 19.0 ft bgs with an average concentration of 4,529 mg/kg. The location of the SEAR sampling event in relation to other soil samples collected after the SSM event is displayed on Figure 8-1.

### 8.2.2 Post Treatment Soil Data

Soil sampling was conducted throughout the duration of the project including: February, April, August, October 2005, and February 2006. In February 2005, samples were collected at 5 and 10 ft bgs (Figure 8-2). Twelve of the nineteen samples collected reported PCE concentrations less than the average of 1,097 mg/kg. Samples above the average of 1,097 mg/kg of PCE within the soil were found in soil mixing columns 5, 13, 36, 143, and 146 (Table 8-2).

In April, two locations were sampled, IS07 and IS08, or column 13 and 143 respectively. Both locations were sampled at 5 and 10 ft bgs. Maximum concentrations of PCE, TCE, and DCE were all found in column 143.

The August 2005 sampling event was conducted at five locations, IS100, IS101, and IS106 – IS108. These locations correspond to mix columns 36, 13, 115, 125, and 143 respectively. Sample depths range from 5 to 20 ft bgs. Maximum concentrations of PCE and TCE were found in column 143 at 20 ft bgs while the maximum concentration of DCE was found in column 125 at 15 ft bgs.

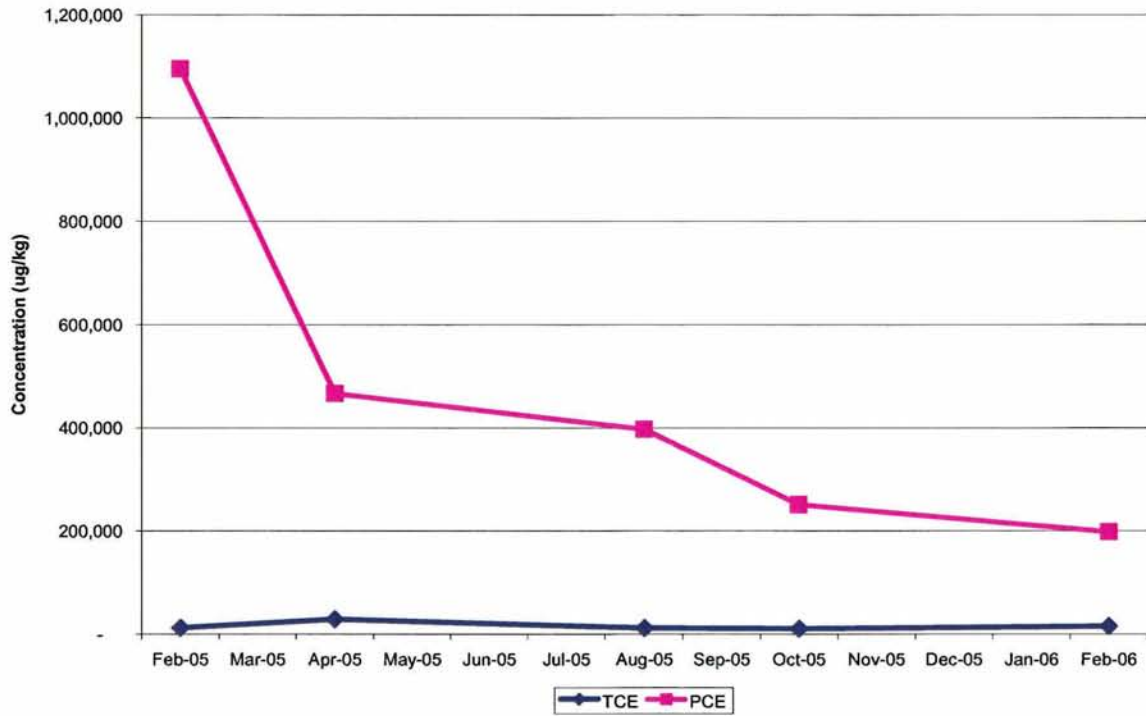
The soil sampling event in October 2005 was coupled with the installation of monitoring wells MW-30 and MW-31. As each well was being installed, soil samples were taken at 5, 10, 15, and 20 ft bgs. High concentrations of PCE, TCE, and DCE were measured in MW-31, which is in column 134. This area coincides with the location in which product has been historically observed in monitoring wells.

Soil samples from this sampling event were also analyzed by CSU to measure the iron content. This analytical work was done to evaluate if ZVI was still present in the treatment area, therefore the reaction could continue. The average iron content in MW30 was 0.84% and in MW31 was 1.29%. These values indicate that ZVI is still present and available for treatment.

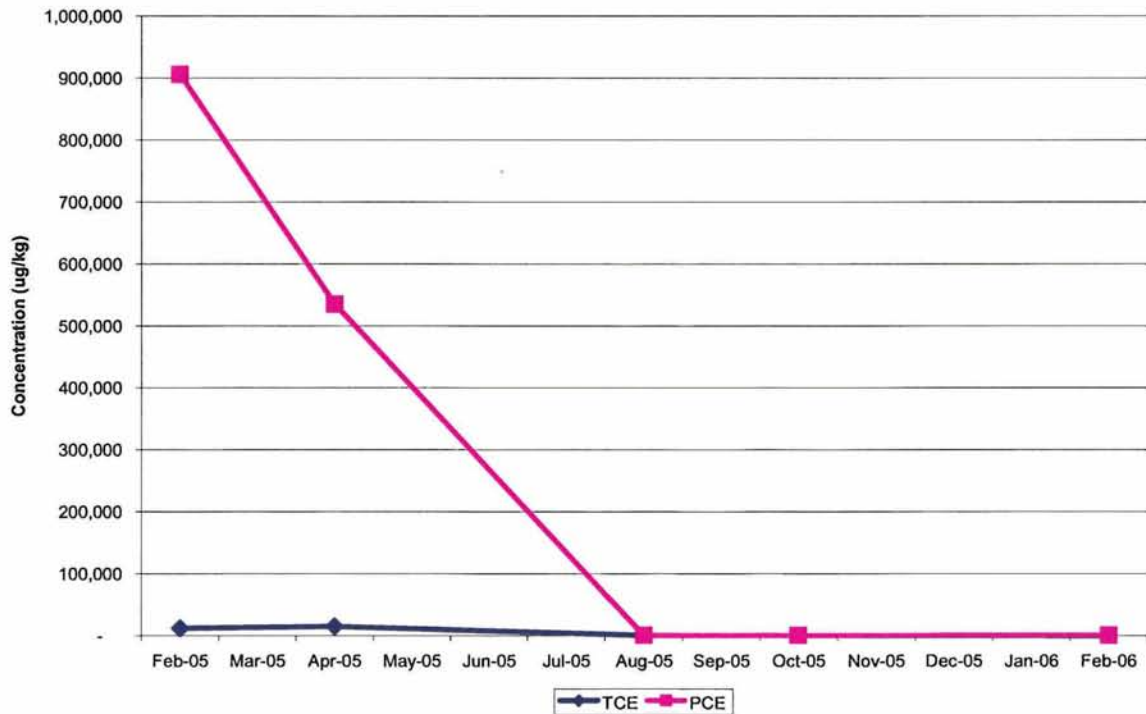
Time-trend charts have been prepared for the treatment area and individual columns examining the average and median soil concentrations during the project.



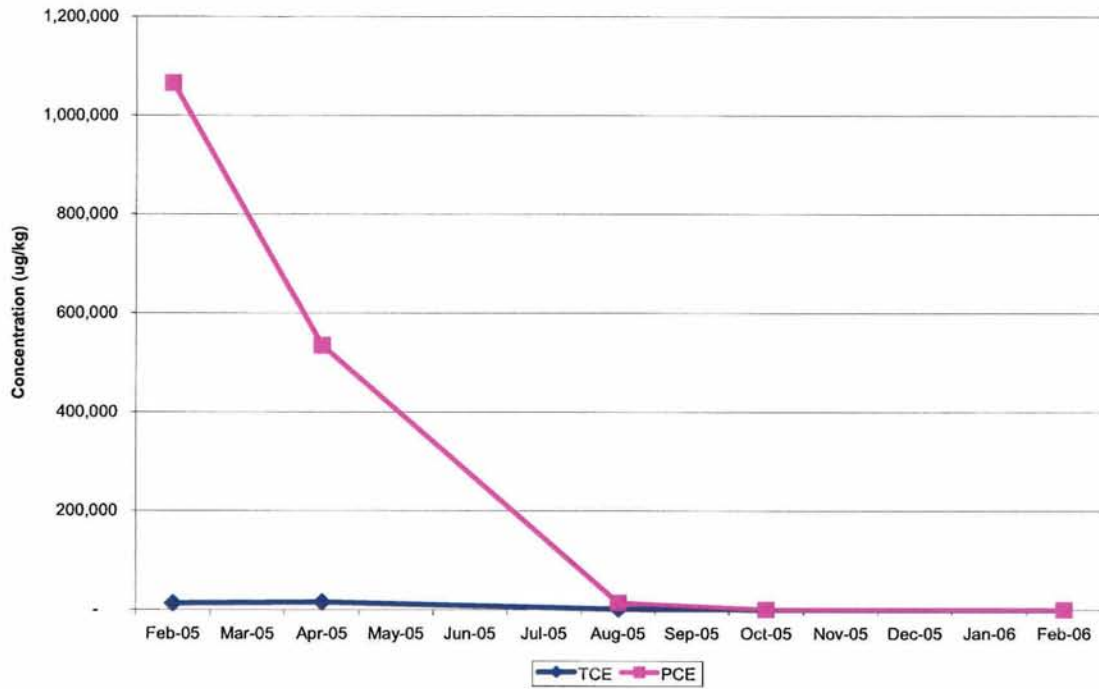
Average Entire Treatment Area Concentrations



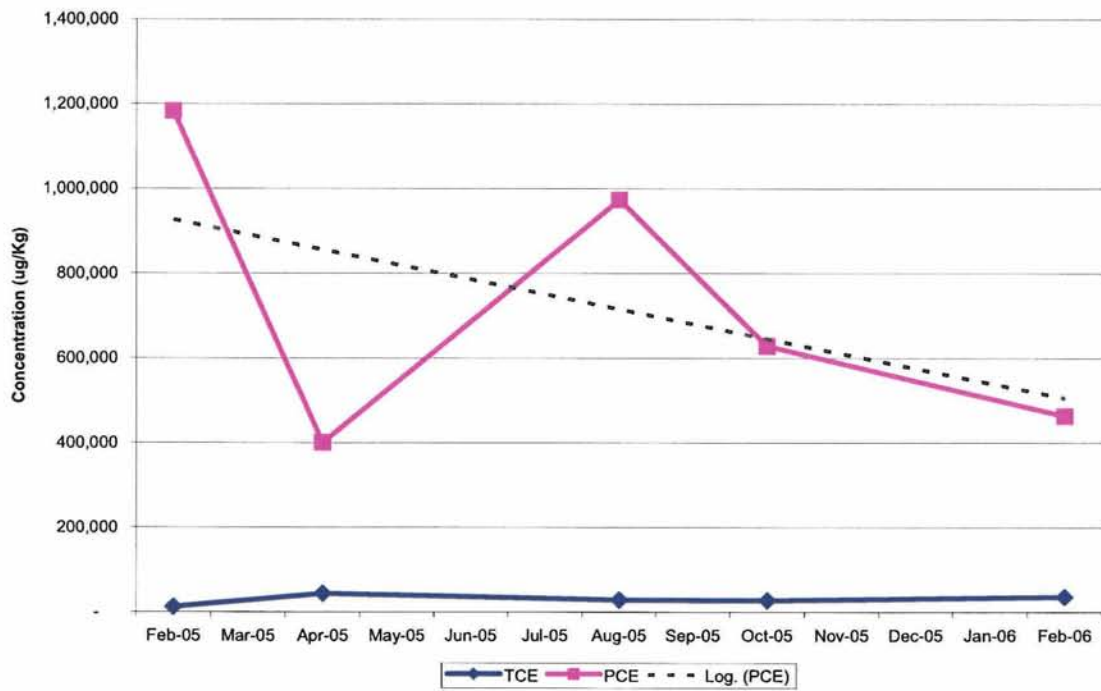
Median Treatment Area Concentrations



### Non-Source Area

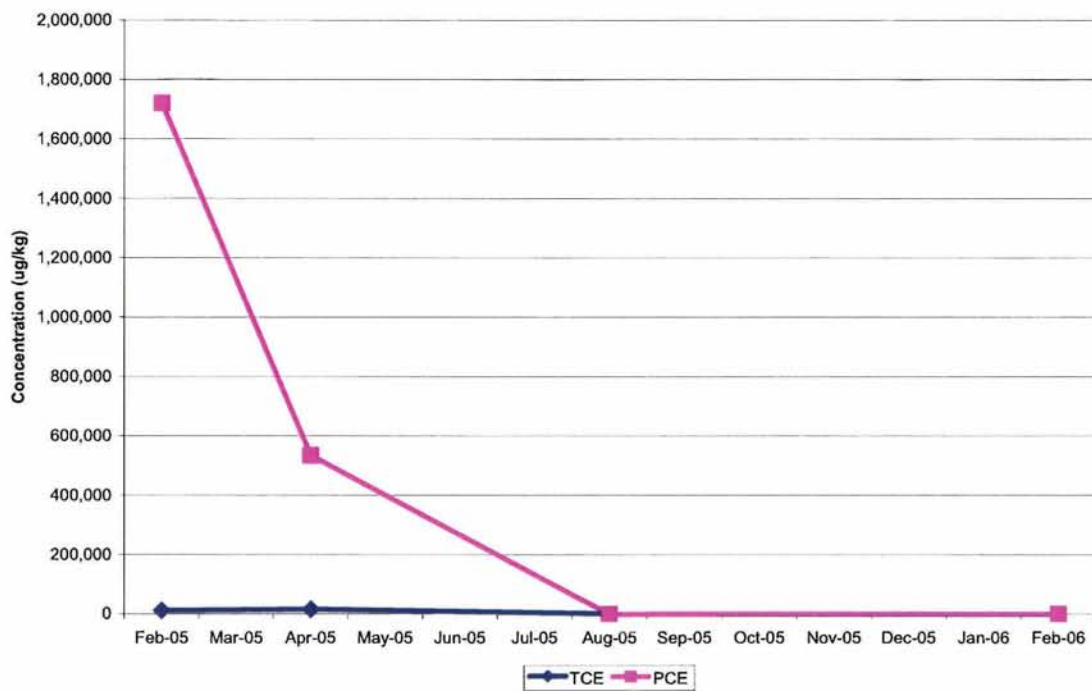


### Source Area

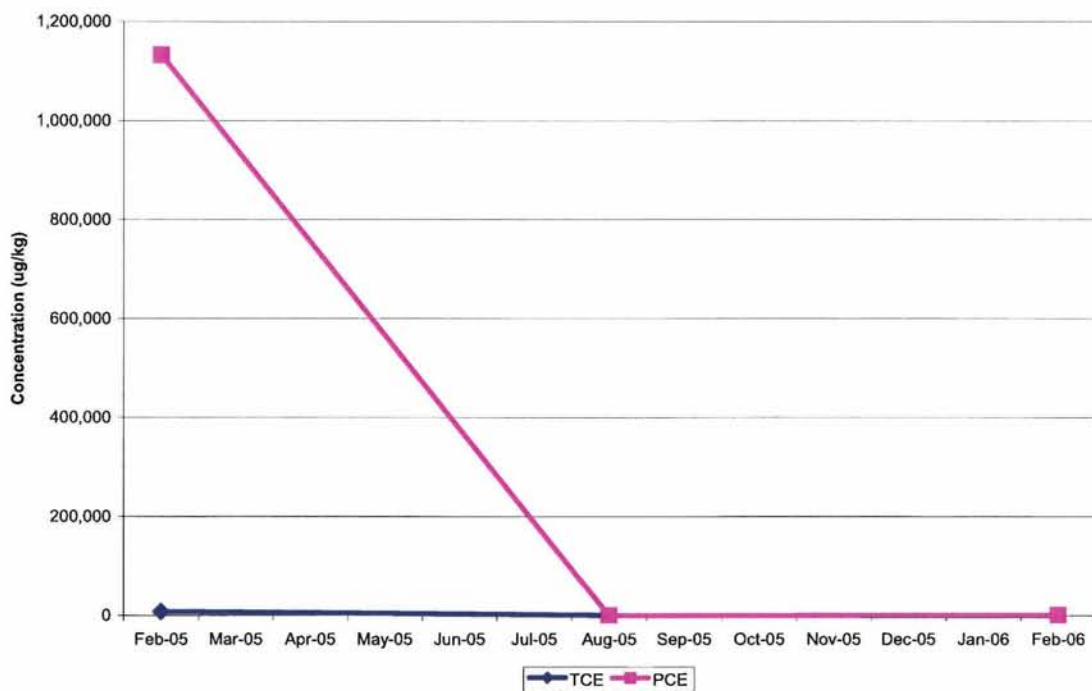




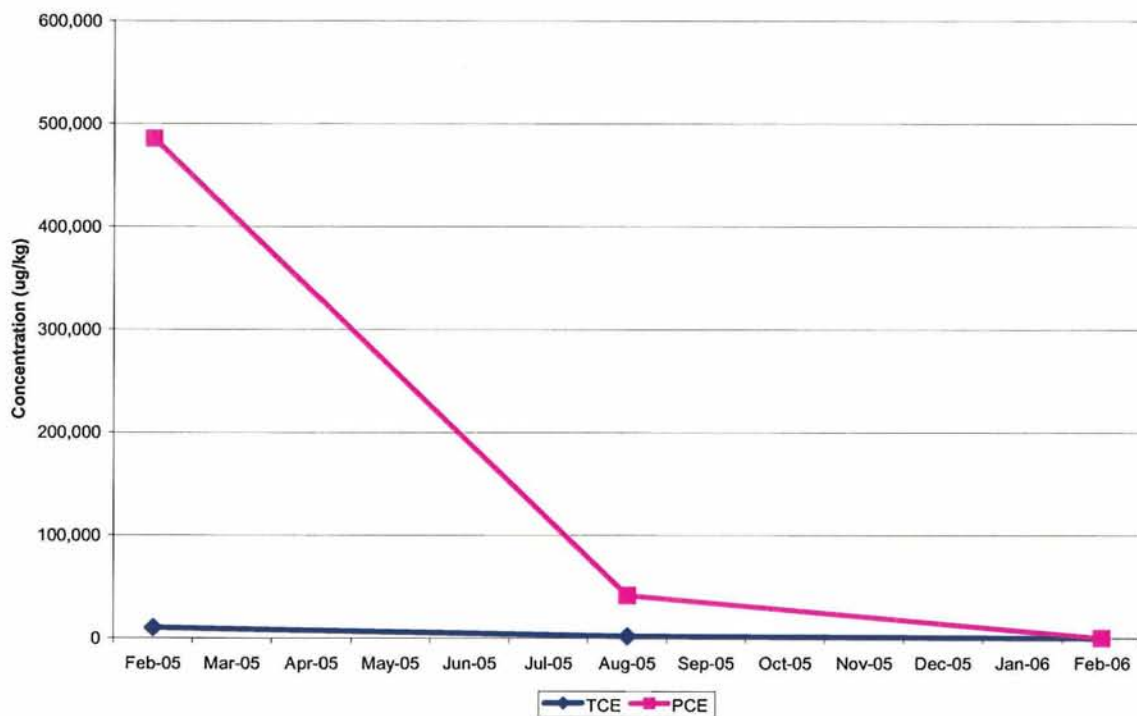
Column 13



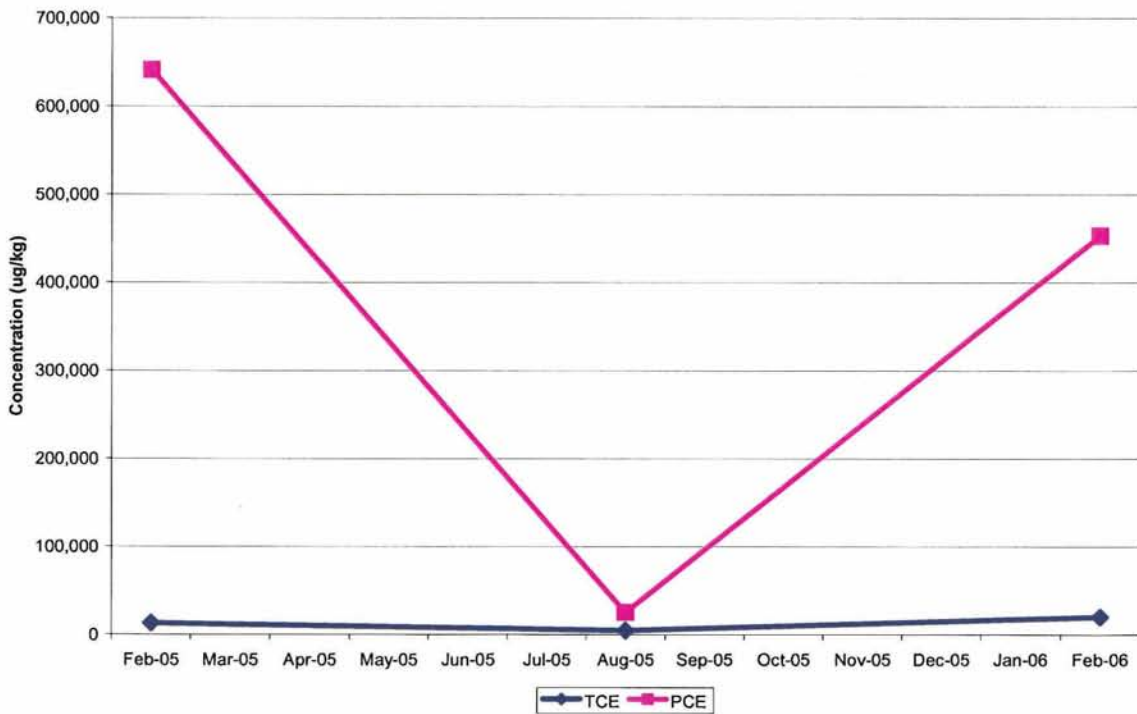
Column 36



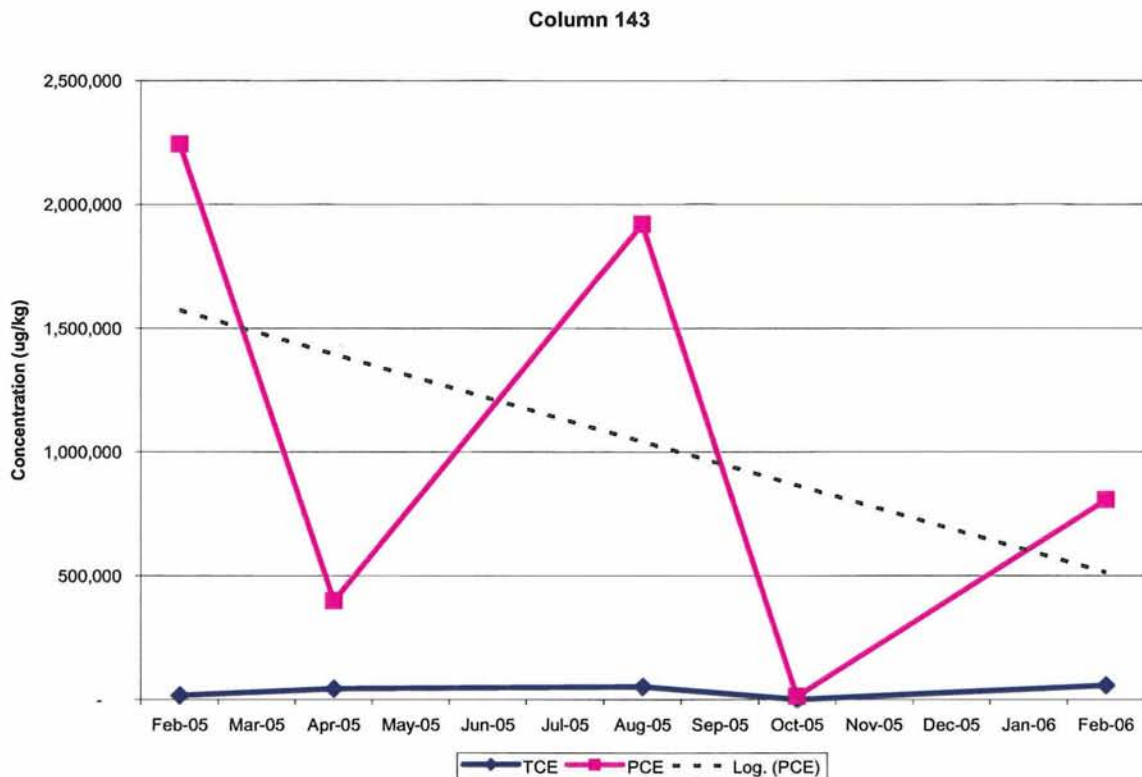
Column 115



Column 125







## 8.3 Groundwater Sampling

### 8.3.1 Baseline Groundwater Data

Supplemental groundwater investigations were conducted in July 2002, September 2003, and April 2004 to identify the major groundwater contaminants of concern and refine previous source area characterization efforts. PCE, TCE, DCE, and VC were all identified. Results from these investigations are provided in **Table 8-3**. Shallow wells within the treatment area historically contained product and were not sampled. Post-SEAR well sampling in 1999 had a highest concentration of 164.1 milligrams per liter (mg/L) in RW06. SEAR wells RW02 and EX04 were sampled during the April 2004 MIP investigation. Results indicate PCE, TCE, and DCE concentrations of 64 mg/L, 37 mg/L, and 39 mg/L respectively with RW02. The location of the SEAR sampling event in relation to other groundwater samples collected after the SSM event is displayed on **Figure 8-1**.

### 8.3.2 Post Treatment Groundwater Data

After mixing, four new monitoring wells were installed within and below the treatment area. Monitoring wells installed included: MW-30, MW-30IW, MW-31, and MW-31IW. In addition, five monitoring wells were installed around the treatment area prior to mixing to observe if any changes or contaminant migration would occur during mixing. Monitoring wells MW-27, MW-28, and MW-29 are located downgradient of the treatment area, while MW-25 and MW-26 are located upgradient of the treatment area (**Figure 8-1**).

The groundwater samples were analyzed for VOCs. Groundwater analytical results are contained in **Table 8-4** and **Figure 8-1**.

In addition, groundwater samples were collected within the treatment area (**Figure 8-1**) during August 2005 with a Geoprobe®. Groundwater samples were collected from soil mix columns 36, 115, and 143 (**Table 8-5**). Soil mix column 143 has had some of the highest PCE concentrations in both soil and groundwater throughout the project. PCE concentrations in the groundwater were 160 mg/L and 3,800 mg/kg in the soil. This location is near MW31. MW31 one year after mixing had its PCE concentration fall to 15 mg/L, while cDCE concentration jumped to 390 mg/L, indicating abiotic degradation is occurring. This represents a 91% reduction in PCE concentration.

PCE was below detection limits for MW30, located in the treatment area, in the November 2005 and February 2006 sampling events. DCE was detected at 1.5 and 1.6 mg/L during the two events.

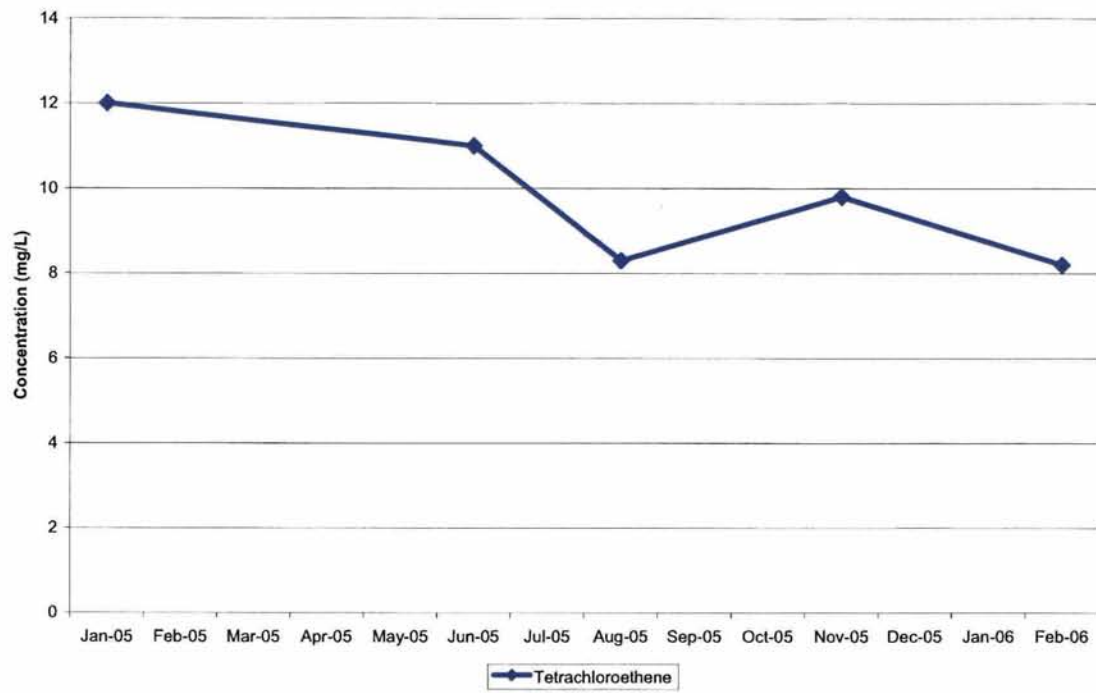
In the two monitoring wells installed below the clay layer of the treatment area, higher levels of PCE, TCE and DCE were found in MW30IW compared to MW31IW. In February 2006, in MW30IW PCE was 1.9 mg/L, TCE was 3.9 mg/L and DCE was 5.7 mg/L. MW31IW had PCE at 0.5 mg/L, TCE at 0.07 and DCE at 0.28 mg/L. MW30IW is downgradient from MW31IW and may have higher concentrations due to all the historic activities at the site and the potential for cross-contamination.

Contaminant concentrations in the downgradient monitoring wells fluctuated during the project. In MW27 and MW28, several constituents did have a slight spike upward, but the concentrations decreased over time. In all three downgradient wells, PCE concentrations after one year were less than initial concentrations. PCE percent reduction was 90% in MW27 and 67% in MW28. DCE concentrations increased in both wells, indicating abiotic degradation. Note that MW29 was destroyed during construction of the parking lot. In general, ORP was negative for the wells during the project, except for MW-28, which went positive six months after treatment was completed. Dissolved oxygen concentrations were not detected.

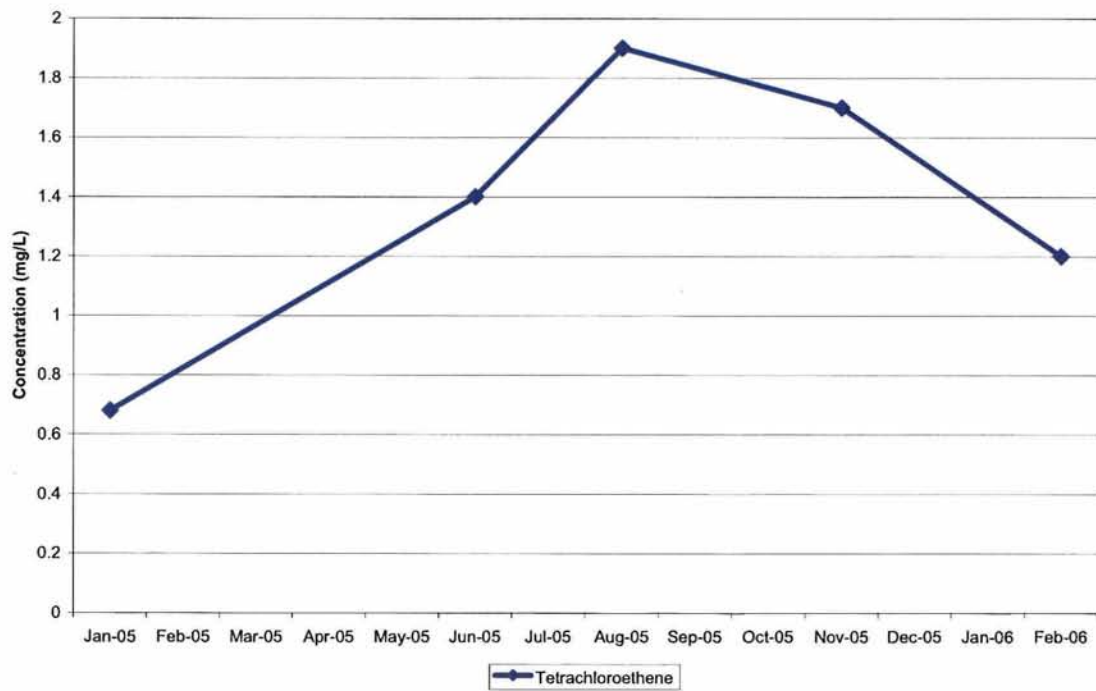
Upgradient monitoring wells had some minimal fluctuation during the project (1 to 4 mg/L), but no appreciable change.

Acetone was found in many of the samples. The acetone is a by-product of the SEAR test and did not help or hinder the treatment process.

MW-25 (Upgradient)

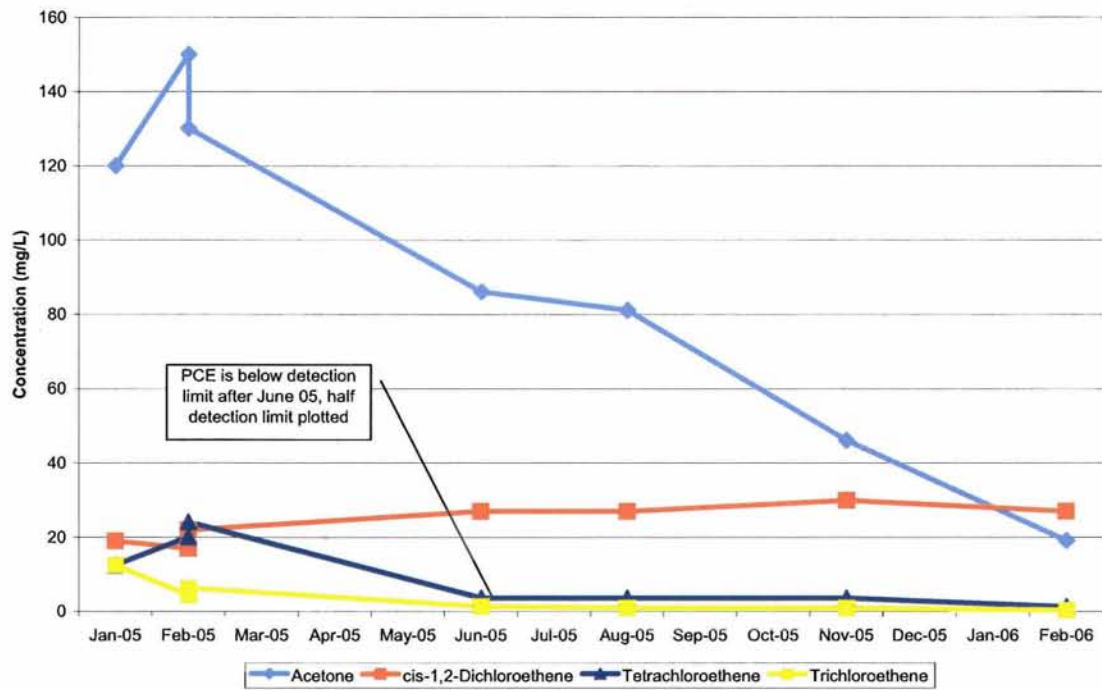


MW-26 (Upgradient)

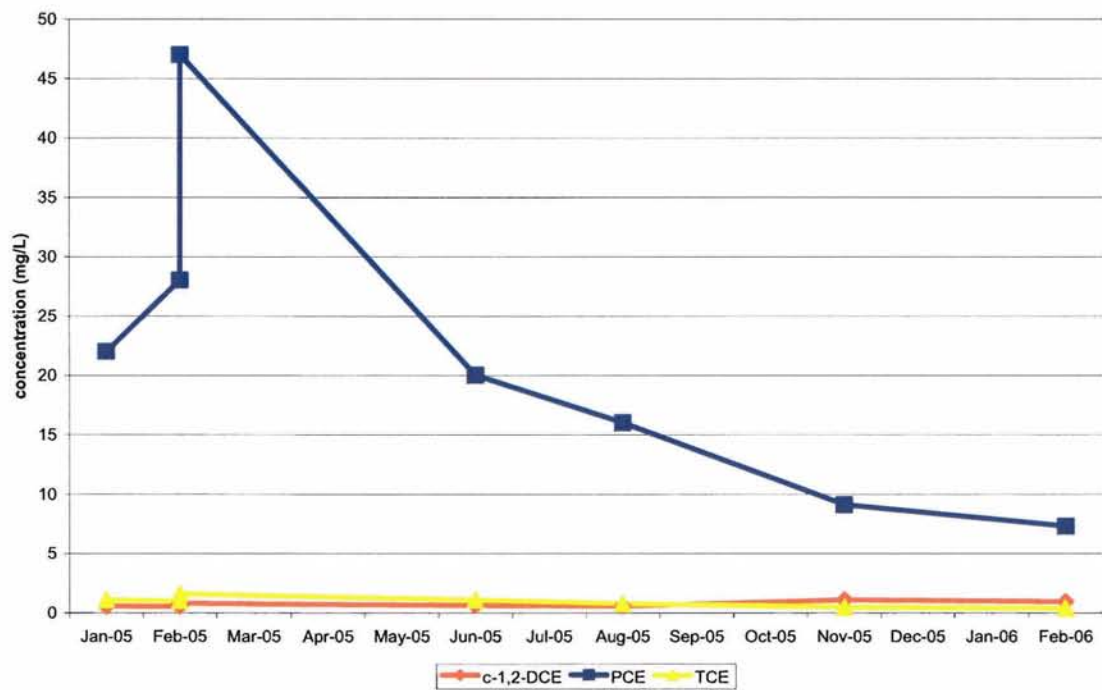




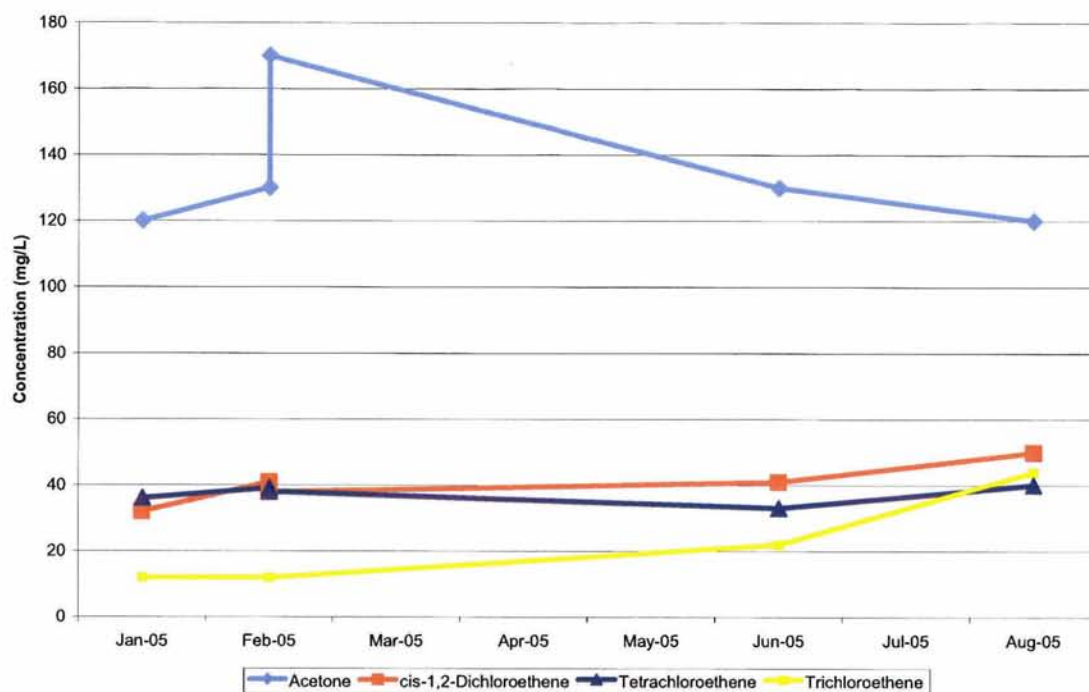
MW27 (downgradient)



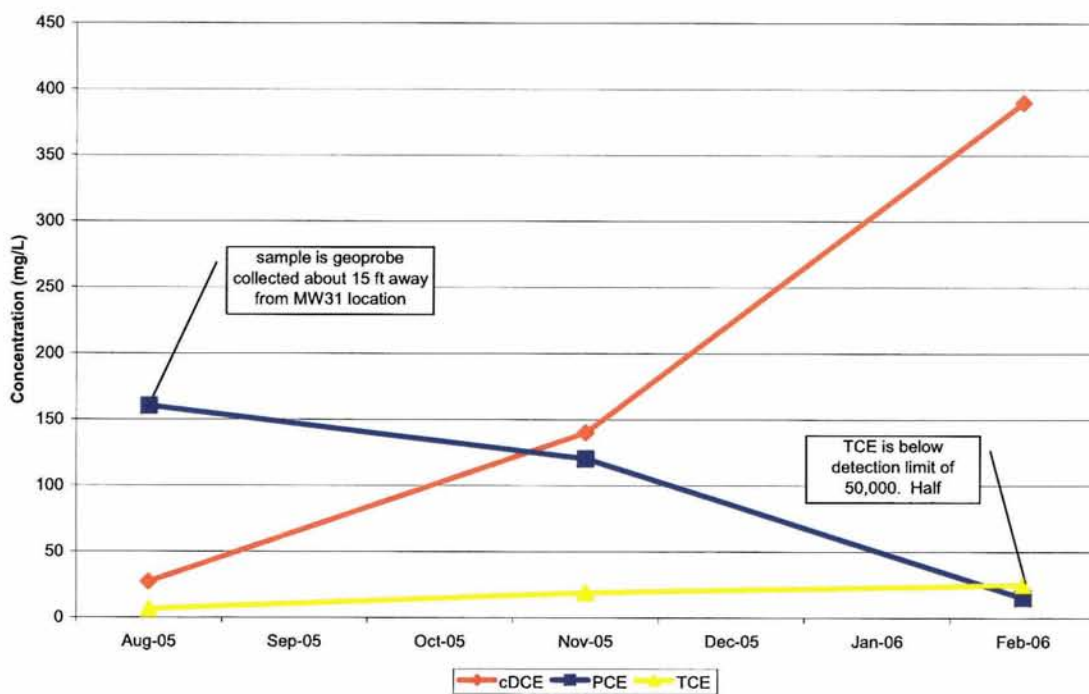
MW28 (Downgradient)



MW29 (downgradient)



MW31 (NAPL Area)



## 8.4 Aquifer Testing

### 8.4.1 Pretreatment Aquifer Testing

CH2M HILL performed aquifer testing (slug tests) on five shallow wells and four intermediate-depth wells during the October 2003 sampling event. Hydraulic conductivities were calculated using the Bouwer and Rice method. Hydraulic conductivities were generally similar between the shallow and intermediate zones. The hydraulic conductivity in the shallow wells ranged from 1.2 to 9.5 feet per day (ft/day) with a geometric mean of 4.1 ft/day. The hydraulic conductivity in the intermediate wells ranged from 2.7 to 9.6 ft/day with a geometric mean of 5.1 ft/day.

### 8.4.2 Post Treatment Aquifer Testing

CH2M HILL performed aquifer testing through the use of rising-head slug tests on three shallow wells in the vicinity of the treatment area on November 15, 2005. The wells tested include: MW-25, upgradient of the treatment area; MW-30, within the treatment area; and MW-28, downgradient of the treatment area.

Hydraulic conductivities were calculated using the Bouwer and Rice method. Hydraulic conductivities of the upgradient and downgradient wells are on the same order of magnitude, 0.12 ft/day and 0.67 ft/day respectively. In contrast, the hydraulic conductivity value for the treatment area well is an order of magnitude lower, 0.013 ft/day or  $4.6 \times 10^{-6}$  cm/s. The soil composition surrounding the treatment area well has a hydraulic conductivity value similar to a clay-silt. With the addition of the ZVI-Clay slurry, the hydraulic conductivity of the soil within the treatment area was reduced. Therefore, the contaminants present within the treatment area are not likely to migrate, but remain within the treatment area where they will decompose with time and when in contact with ZVI.

## 8.5 Membrane Interface Probe Sampling

### 8.5.1 Baseline MIP Data

Since the dry cleaning solvents released around Building 25 are predominantly chlorinated hydrocarbons, the primary MIP response was observed on the ECD. The maximum range of the ECD detector was frequently exceeded. Elevated PID responses and to a lesser degree FID responses were also observed in areas known to contain NAPL. For this reason, the PID and FID responses were used in concert with the ECD to evaluate the presence of heavily impacted soil and groundwater.

As previously stated, the initial MIP borings were advanced in areas of known free product accumulations. The detector responses from these borings indicated that ECD, PID and FID responses of greater than approximately  $1.2 \times 10^6 \mu\text{V}$ ,  $1.0 \times 10^6 \mu\text{V}$ , and  $4.5 \times 10^5 \mu\text{V}$ , respectively, likely indicated the presence of free product. Also, in areas of known free product accumulation, the form of the detector response was often seen to be 'flat-topped' i.e. sufficient contaminant mass was encountered to maintain a constant detector response.

The information provided by the MIP investigation was used to generate **Figure 1-7**, which illustrates the estimated horizontal extent of the source area, i.e. the area of ECD responses exceeding  $1.0 \times 10^6 \mu\text{V}$  and PID responses greater than 100,000  $\mu\text{V}$ . **Figure 1-8** displays the orientation of the cross section shown by **Figure 1-9**. **Figure 1-10** presents the vertical



distribution of VOCs (as detected by the MIP PID) along the B-B' cross section. **Figures 1-11, 1-12, and 1-13** display the MIP PID response at 10 feet bgs, 15 feet bgs, and 20 feet bgs, respectively. The vertical distribution of DNAPL in the source area is presented on **Figure 1-14**.

Groundwater samples from SEAR wells RW02 and EX04 were obtained during the MIP investigation. Analytical results of these samples are presented in **Table 8-3**. Detections from these samples indicate high concentrations of PCE, TCE, 1,2-DCE, and VC are still present in the SEAR demonstration area.

#### **8.5.2 Post Treatment MIP Data**

In March 2006, a focused MIP investigation was performed in the treatment area. The intent of this investigation was to compare post-treatment results to pretreatment results. Sixteen MIP borings were advanced to 20 ft bgs within the treatment area.

The general results of the MIP were elevated readings on the ECD and PID. The results are qualitative and due to the nature of MIP, no definitive conclusions can be drawn. The post-treatment concentrations still saturated the MIP detectors. The results are similar to the baseline results, with the primary hot spot under the building. Although there is contaminant reduction at the site based on lab data, the MIP may not be sensitive enough to detect the reduction.

## 9. Construction Issues

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### 9.1 Insufficient Mixing Within Treatment Area

A DPT soil sampling investigation was conducted from August 3-4, 2005. The purpose of the investigation was to collect soil samples and examine how well the soil was mixed to depth. Continuous soil cores were collected from 12 locations within the treatment area. In addition to lithologic characterization of the soils, analytical samples were collected from five of the locations at varying depths.

Figure 9-1 shows the locations of the soil borings in relation to specific mixing columns. Each location was located using a sub-meter GPS unit in order to confirm the proper sample locations. Following the advancement of the first two borings, it was noted that there was several inches of unmixed silty sand below the mixed soil and above the native clay layer. Once the unmixed sandy layer was discovered in borings IS100 and IS101, the approach of the sampling effort was modified. In order to determine the extent of the sandy layer, 4 additional borings were advanced at intervals of 25 ft. along an NW-SE transect across the treatment area. The results of these additional borings indicated that mixing had occurred to the depth of the clay layer for a majority of the site.

Incomplete mixing was identified in 5 of the 12 borings advanced at the site. Borings which exhibited incomplete mixing include IS-100, IS-101, IS-109, IS-110, and IS-111. The unmixed portion ranged from two to ten inches. This corresponds to approximately 1 to 4.5% of these columns not being adequately mixed. The unmixed borings were all in the western most portion of the site, where product had not been observed. Table 9-1 summarizes the depths of mixing for the 12 DPT soil borings.

In general, the soils of the unmixed zone consisted of saturated silty fine sand. Below the sand, the native silty clay was encountered. The mixed soils were generally dark gray to black clay and fine sand. The mixed soils tended to be soft and very wet.

The probably reason for the incomplete mixing is the auger was advanced several inches short of the clay layer. A secondary potential reason may be a slight dipping of the clay layer away from the treatment area. The potential area with incomplete mixing represents approximately 25% of the columns. Assuming 3% of those columns were not mixed, approximately 50 cy out of 7,000 cy was not mixed.

**TABLE 9-1**

Post Treatment Source Area DPT Sampling Summary

*Operable Unit No. 15 – Building 25 Non-Time Critical Removal Action Report*

Boring ID	Column ID	Mixed to Depth	Unmixed Interval
IS-100	36	No	18-18.9 ft bgs
IS-101	13	No	18.5-18.9 ft. bgs
IS-102	49	Yes	NA
S-103	63	Yes	NA
IS-104	86	Yes	NA
IS-105	109	Yes	NA
IS-106	115	Yes	NA
IS-107	125	Yes	NA
IS-108	143	Yes	NA
IS-109	31	No	18-18.6 ft. bgs
IS-110	12	No	18-18.6 ft bgs
IS-111	41	No	18-18.2 ft bgs

## 9.2 Discharge of Contact Water Into Storm Sewer

At 7:30 a.m. on Wednesday April 27, 2005, the project manager was notified by representatives of MCB Camp Lejeune that contact water from the treatment area was discharged to a nearby stormwater drain.

The incident occurred on April 26, 2005 while the AGVIQ crew was stabilizing the treatment area. Approximately 200 gallons of water was pumped into a nearby stormwater catch basin. At that time the pumping was stopped in order to sample the water and sediment in the catch basin for VOCs. The remaining ponded water was then pumped into a 20,000-gallon frac tank. Water samples collected from the frac tank in April 2005 indicated the presence of PCE at a concentration of 1,610 µg/L, TCE at a concentration of 1,140 µg/L, and cis-1,2-DCE at a concentration of 6,410 µg/L.

Based on these events, a treatment system was brought to the site. Any contact water was collected in the frac tank was pumped through a 25 micron bag filter to remove suspended solids from the water stream, and then pumped through a 500-pound liquid-phase granular activated carbon (LGAC) vessel. The treated water was then discharged into the Base's sanitary sewer system. Approximately 100,000 gallons of stormwater were treated over four months.

Sediment samples were collected from nearby catch basins and analyzed for VOCs. The sediments were found to contain VOCs. Once the length of pipe containing sediment contaminated with chlorinated solvents was identified, the sewers were cleaned and all



water and sediment collected and disposed of accordingly. Cleaning was conducted by jetting the sewers, upward to the discharge points (clean to dirty).

Below is a summary of the analytical results from stormwater and sediment samples collected in the catch basin. Stormwater-1 represents the liquid pumped down the storm sewer. Storm sed-1 is a sediment sample from the catch basin where the stormwater was pumped. Storm sed-2 is a sediment sample collected from the catch basin downgradient of the existing storm water drain pipe where the plug apparently failed. **Figure 9-2** shows the sediment sample locations and the portion of the stormwater sewer that was cleaned.

**TABLE 9-2**

Stormwater Release Incident Analytical Results

Operable Unit No. 15 – Building 25 Non-Time Critical Removal Action Report

Constituent	Stormwater-1	Storm Sed-1	Storm Sed-2
Units	µg/L	µg/kg	µg/kg
% Solids	---	10.1	70.2
Acetone	532 J	BQL	BQL
c-1,2 DCE	6,410	8,400	9,550
PCE	1,610	2,940	710
TCE	1,140	1,280	46.6 J

Sediment results reported on a dry basis.

BQL – Below Quantity Limit

### 9.3 Injury

On Thursday January 20, 2005 at approximately 10:50 am, there was an incident on the site involving an All-Crane employee, subcontractor of Williams Environmental Services. The Subcontractor was onsite to assemble a crane. The foreman's arm was entangled in the cables on the crane as the counter weight was being lifted. The worker went to the hospital and was released the same day with abrasions and puncture wound to his left wrist. All crane assembly ceased until an investigation had been performed.

## 10. Cost

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All costs displayed are the final costs charged to the project and client, with company profit included. As expected, the majority of the costs are divided amongst the treatment of the source area via soil mixing and the accompanying site restoration. The remainder of the charges stem from site preparation, project design and treatability study, and management and reporting. The following table lists the cost for each sector of the project and their respective percentages of the project total.

**TABLE 10-1**

Project Cost Information

*Operable Unit No. 15 – Building 25 Non-Time Critical Removal Action Report*

Sector	Cost	Percent of Total Cost
Management and Reporting	\$177,687.42	9%
Design and Treatability Study	\$129,708.42	7%
Site Preparation	\$177,190.64	9%
Soil Mixing, Oversight and Monitoring	\$972,831.44	50%
Site Restoration	\$504,376.27	26%
<b>Total Cost</b>	<b>\$1,961,794.19</b>	

# 11. Observations/Conclusions

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This section summarizes observations from the Site 88 NTCRA.

## 11.1 Observations/Conclusions

Observations made based on the results of the Site 88 NTCRA are as follows:

- Within the treatment area PCE concentrations within the soil were significantly reduced after one year. Reduction was as follows:
  - ❖ Average concentrations of entire treatment area – 81.9%
  - ❖ Median concentration of entire treatment area – 99.9%
  - ❖ Source area (area with observed NAPL) – 60.8%
  - ❖ Non-source area (area without observed NAPL) – 99.9%
  - ❖ Weighted average (22% source area, 78% non-source area) – 91.4%
- Reduction of areas with observed NAPL was less than areas that had no NAPL. Reasons may include:
  - ❖ A much higher initial concentration requiring reduction
  - ❖ Slower reaction kinetics associated with NAPL
  - ❖ NAPL possibly coating the ZVI, thus hindering the reaction
  - ❖ NAPL being slow to dissolve into water, thus slowing the reduction reaction
- ZVI is still present in the treatment area. Testing indicated iron content of 0.84% and 1.29% at the two sample locations.
- Soil gas analysis indicates a reduction of PCE concentration within the treatment area has an average reduction of 99% seven months after mixing.
- Prior to treatment, groundwater in the target area had a PCE concentration of 64 mg/L. This did not represent monitoring wells with product. Groundwater samples collected by direct push methods after six months had PCE concentrations from 1.5 to 160 mg/L. Groundwater samples collected nine months after mixing; from MW-30 and MW-31 indicate PCE concentrations of below detection limit and 120 mg/L respectively. After one year, the PCE concentration in MW-30 was still below detection limits, while the PCE concentration in MW-31 was 15 mg/L, representing a 91% reduction of PCE. The concentration of DCE increased to 390 mg/L after one year in MW-31, indicating abiotic degradation is taking place. MW-31 is located where product was observed.



- Downgradient water quality was not adversely impacted by mixing or the treatment process. The presence of acetone is a by-product of the SEAR test. There were some increase in several constituents, but the concentrations decreased over time to a level below initial concentrations. PCE reduction of 90% and 67% were observed.
- The action was effective at reducing contaminant mobility. Hydraulic conductivity within the treatment area (MW-30) was reduced 50 to 400 times (one to two orders of magnitude). Post-treatment hydraulic conductivity is 0.013 ft/day, compared to 0.67 ft/day at MW-28, and 0.12 ft/day at MW-25 which are outside the treatment area and compared to a mean hydraulic conductivity value of 4.1 ft/day in shallow wells before mixing.
- There were no air emissions during the treatment process. Contaminant vapors were easily captured and treated in an onsite carbon system.
- Implementation time was approximately 9 months. This timeframe was from fencing the site to demolish the slab to completing the parking lot.
- A new 38,000 square foot parking lot has been installed at the Base that has provided 65 new parking spaces and caps the treatment area.
- Much of the project cost was associated with preparing the site and site restoration. These activities were necessary due to the age, location and end use of the site. Roughly 33 to 40% of the project costs were associated with these logistical issues.

## 11.2 NTCRA Objectives and Goals

The NTCRA was successful in meeting the established objectives and goals. Contaminant volume and mobility have been significantly reduced. Within the treatment area, the overall mass of the contaminant plume was reduced by greater than 90%. The mixing activities took place within three weeks once the site had been prepped, i.e. abandonment of utilities and excavation and removal of the foundation of former Building 25. Further, Site 88 has been fully restored, installing water, steam, and power lines to supply Buildings 37 and 43 as well as paving a new parking lot over the treatment area.

## 11.3 Lessons Learned

Several lessons learned include:

- Design the monitoring program to collect samples immediately after mixing to obtain more accurate initial concentration
- Consistently collect more samples, both soil and water, over time at the same locations
- Plan on managing stormwater, through covering the treatment area or installing a sump with a small treatment system
- Over design/estimate the mixing depth, where possible, but cannot compromise any confining layers

- In mixing in areas with observed product, perform additional mixing and add additional ZVI as a safety factor

## 12. References

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*Guidance on Conducting Non-Time Critical Removal Actions Under CERCLA.* EPA/540-R-93-057, OERR, USEPA, August 1993.

*Final Focused Remedial Investigation Report Operable Unit no. 15 (Site 88).* Baker Environmental, Inc., May 15, 1998.

*Work Plan for a Partitioning Interwell Tracer Test.* Duke Engineering and Services, Inc. October 31, 1997.

*Contractor's Closeout Report Underground Storage Tank Removals at Building 25 MCB Camp Lejeune Jacksonville, North Carolina.* OHM Remediation Services Corporation, October 1996.

*Surfactant-Enhanced Aquifer Remediation Demonstration at Site 88, Marine Corp Base Camp Lejeune, North Carolina.* Duke Engineering and Services, January 2000.

*DNAPL Site Characterization using a Partitioning Interwell Tracer Test at Site 88, Marine Corps Base, Camp Lejeune, North Carolina.* Duke Engineering and Services, July 1999.



**TABLE 1-2**  
**SHALLOW TEMPORARY WELL CONCENTRATIONS**  
 OPERABLE UNIT NO. 15 - BUILDING 25  
 MCB CAMP LEJEUNE, NORTH CAROLINA

Sample ID	Sample Date	PCE (mg/L)	TCE (mg/L)	cis-1,2-DCE (mg/L)
IR88-TW01	8/1/1996	157	18	ND
IR88-TW02	8/1/1996	649	82	445
IR88-TW03	8/1/1996	14,090	838	1,184
IR88-TW04	8/1/1996	32,839	230	ND
IR88-TW05	8/16/1996	1,382	21	ND
IR88-TW08	8/17/1996	53,704	341	271
IR88-TW09	8/17/1996	969	71	ND
IR88-TW11	8/17/1996	1	ND	ND
IR88-TW12	8/17/1996	2	ND	ND
IR88-TW13	8/17/1996	44	ND	ND
IR88-TW15	8/18/1996	4,932	3,031	3,725
IR88-TW22	4/21/1997	54,882	125	126

**TABLE 1-3**  
**PRE-SEAR SOIL BORING CONCENTRATIONS**  
 OPERABLE UNIT NO. 15 - BUILDING 25  
 MCB CAMP LEJEUNE, NORTH CAROLINA

Sample ID	Sample Date	Depth	Soil Concentration (mg/kg)			f <sub>oc</sub>	DNAPL Saturation (%)
			PCE	TCE	DCE		
IR88-IS01-1	07/25/97	5.3	ND	ND	19.0	0.0015	0.0
IR88-IS01-2	07/25/97	8.1	72.8	6.9	43.3	0.0015	0.0
IR88-IS01-3	07/25/97	8.6	101.4	38.6	49.9	0.0015	0.0
IR88-IS01-4	07/25/97	10.1	114.0	8.4	35.1	0.0015	0.0
IR88-IS02-1	07/25/97	8.1	13.1	2.1	15.1	0.0015	0.0
IR88-IS02-2	07/25/97	8.6	0.7	3.0	3.2	0.0015	0.0
IR88-IS02-3	07/25/97	8.9	64.8	ND	49.5	0.0015	0.0
IR88-IS02-4	07/25/97	16.3	0.1	ND	ND	0.0015	0.0
IR988-IS03-1	07/25/97	2.6	16.9	0.5	ND	0.0015	0.0
IR988-IS03-2	07/25/97	5.9	1.2	ND	ND	0.0015	0.0
IR988-IS03-3	07/25/97	7.6	7.2	ND	0.2	0.0015	0.0
IR88-IS04-1	07/26/97	12.1	7.3	ND	ND	0.0015	0.0
IR88-IS05-1	07/26/97	2.6	209.0	ND	ND	0.0015	0.0
IR88-IS05-2	07/26/97	5.7	653.0	ND	ND	0.0015	0.2
IR88-IS05-3	07/26/97	8.2	3508.0	ND	ND	0.0015	1.0
IR88-IS05-4	07/26/97	10.3	372.0	25.4	ND	0.0015	0.1
IR88-IS06-1	07/26/97	9.2	3.2	ND	ND	0.0015	0.0
IR88-IS07-1	07/26/97	5.1	0.1	ND	3.6	0.0015	0.0
IR88-IS07-2	07/26/97	8.6	195.0	6.9	81.5	0.0015	0.0
IR88-IS07-3	07/26/97	11.0	58.0	4.0	32.6	0.0015	0.0
IR88-IS07-4	07/26/97	18.4	1901.0	ND	ND	0.0060	0.4
IR88-IS08-1	07/27/97	17.6	13748.0	ND	ND	0.0015	4.2
IR88-IS08-2	07/27/97	18.7	5997.0	ND	ND	0.0060	1.7
IR88-IS08-3	07/27/97	19.4	2617.0	ND	ND	0.0060	0.7
IR88-IS08-4	07/27/97	4.7	1268.0	133.0	ND	0.0015	0.4
IR88-IS08-5	07/27/97	7.3	1577.0	258.0	ND	0.0015	0.5
IR88-IS09-1	07/27/97	10.6	188.0	ND	ND	0.0015	0.0
IR88-IS09-2	07/27/97	14.7	24.0	ND	ND	0.0015	0.0
IR88-IS10-1	07/27/97	15.4	80.0	3.7	3.7	0.0015	0.0
IR88-IS10-2	07/27/97	16.2	20.0	0.6	0.8	0.0015	0.0
IR88-IS10-3	07/27/97	17.2	25829.0	ND	ND	0.0015	7.9
IR88-IS10-4	07/27/97	17.7	3841.0	ND	ND	0.0060	1.0
IR88-IS11-1	07/27/97	16.4	12169.0	ND	ND	0.0060	3.6
IR88-IS12-1	08/19/97	15.6	52.0	ND	ND	0.0015	0.0
IR88-IS12-2	08/19/97	16.1	22.0	0.2	ND	0.0060	0.0
IR88-IS12-3	08/19/97	17.1	32.0	ND	ND	0.0015	0.0

PCE - Tetrachloroethene  
 TCE - Trichloroethene  
 DCE - Dichloroethene  
 mg/kg - milligrams per kilogram  
 f<sub>oc</sub> - fraction organic carbon  
 NAPL - Non-aqueous phase liquid



**TABLE 1-3**  
**PRE-SEAR SOIL BORING CONCENTRATIONS**  
 OPERABLE UNIT NO. 15 - BUILDING 25  
 MCB CAMP LEJEUNE, NORTH CAROLINA

Sample ID	Sample Date	Depth	Soil Concentration (mg/kg)			f <sub>oc</sub>	DNAPL Saturation (%)
			PCE	TCE	DCE		
IR88-IS13-1	08/19/97	17.1	7760.0	ND	ND	0.0015	2.3
IR88-IS13-2	08/19/97	17.6	25411.0	ND	ND	0.0015	7.9
IR88-IS13-3	08/19/97	18.1	6226.0	ND	ND	0.0015	1.9
IR88-RW01-01	08/19/97	17.1	31.0	ND	ND	0.0015	0.0
IR88-RW01-02	08/19/97	18.1	11337.0	ND	ND	0.0060	3.3
IR88-RW01-03	08/19/97	20.1	1483.0	ND	ND	0.0060	0.3
IR88-RW02-01	08/19/97	17.1	16.0	ND	ND	0.0015	0.0
IR88-RW02-02	08/19/97	18.1	1049.0	ND	ND	0.0015	0.3
IR88-RW02-03	08/19/97	18.6	4634.0	ND	ND	0.0060	1.3
IR88-IW01-01	08/20/97	17.6	138.0	ND	ND	0.0015	0.0
IR88-IW01-02	08/20/97	18.1	33572.0	ND	ND	0.0060	10.2
IR88-IW01-03	08/20/97	18.6	5140.0	ND	ND	0.0060	1.4
IR88-IW01-06	08/20/97	4.2	1.7	ND	22	0.0015	0.0
CPT01-2	11/15/97	15.2	ND	ND	ND	NA	0.0
CPT02-2	11/15/97	17.2	ND	ND	ND	NA	0.0
CPT03-2	11/15/97	18.2	32.0	ND	ND	0.0060	0.0
CPT04-2	11/15/97	18.2	60.0	ND	ND	0.0060	0.0
CPT05-2	11/15/97	19.5	1.3	0.1	ND	0.0060	0.0
CPT07-2	11/15/97	17.0	3.9	0.3	ND	0.0015	0.0
CPT08-2	11/15/97	21.0	8.0	0.3	ND	0.0060	0.0
CPT09-2	11/15/97	17.6	3.0	ND	ND	0.0015	0.0
CPT10-2	11/15/97	18.4	0.5	ND	ND	0.0015	0.0
IS14-2	11/18/97	18.0	0.05	ND	ND	0.0060	0.0
IS15-2	11/18/97	19.0	3.4	0.05	ND	0.0015	0.0
IS16-2	11/19/97	18.5	3261.0	ND	ND	0.0060	0.9
IS17-2	11/19/97	18.0	5930.0	ND	ND	0.0015	1.8
IS18-2	11/19/97	18.4	5.4	0.1	ND	0.0060	0.0
IS19-2	11/19/97	17.4	0.1	ND	ND	0.0015	0.0
IS20-2	11/19/97	18.5	2.9	ND	ND	0.0015	0.0
IS21-3	11/20/97	19.7	908.0	ND	ND	0.0015	0.2
IS21-4	11/20/97	18.7	8763.0	ND	ND	0.0015	2.6
IS22-2	11/20/97	17.0	3603.0	ND	ND	0.0015	1.1
IS22-3	11/20/97	18.0	2815.0	ND	ND	0.0015	0.8
IS22-4	11/20/97	19.0	909.0	ND	ND	0.0060	0.1
IS23-1	11/20/97	17.5	9.3	ND	ND	0.0015	0.0
IS23-2	11/20/97	18.2	1476.0	ND	ND	0.0015	0.4
IS23-3	11/20/97	19.0	311.0	ND	ND	0.0060	0.0
IS25-2	11/21/97	17.0	1709.0	ND	ND	0.0015	0.5
IS25-3	11/21/97	18.0	10851.0	ND	ND	0.0060	3.2
IS25-4	11/21/97	19.0	814.0	ND	ND	0.0060	0.1

PCE - Tetrachloroethene  
 TCE - Trichloroethene  
 DCE - Dichloroethene  
 mg/kg - milligrams per kilogram  
 foc - fraction organic carbon  
 NAPL - Non-aqueous phase liquid



**TABLE 1-3**  
**PRE-SEAR SOIL BORING CONCENTRATIONS**  
 OPERABLE UNIT NO. 15 - BUILDING 25  
 MCB CAMP LEJEUNE, NORTH CAROLINA

Sample ID	Sample Date	Depth	Soil Concentration (mg/kg)			f <sub>oc</sub>	DNAPL Saturation (%)
			PCE	TCE	DCE		
IS26-1	11/21/97	17.0	208.0	ND	ND	0.0060	0.0
IS26-2	11/21/97	17.7	1611.0	ND	ND	0.0015	0.4
IS26-3	11/21/97	18.5	106.0	ND	ND	0.0060	0.0
IS29-2	11/22/97	18.8	4361.0	ND	ND	0.0060	1.2
IS30-2	11/22/97	18.8	3212.0	ND	ND	0.0060	0.8
IS31-2	11/22/97	16.8	54.0	ND	ND	0.0060	0.0
EX01-1	12/03/97	16.5	3013.0	ND	ND	0.0015	0.9
EX01-2	12/03/97	17.5	44352.0	ND	ND	0.0015	13.7
EX01-3	12/03/97	18.5	29763.0	ND	ND	0.0015	9.1
EX03-1	12/04/97	16.0	1.2	ND	ND	0.0015	0.0
EX03-2	12/04/97	17.5	19.0	ND	ND	0.0015	0.0
EX03-3	12/04/97	19.0	96.0	ND	ND	0.0015	0.0
EX04-1	12/04/97	17.0	122.0	1.8	2.2	0.0015	0.0
EX04-2	12/04/97	18.5	25.0	ND	ND	0.0015	0.0
EX04-3	12/04/97	19.5	11743.0	ND	ND	0.0015	3.6
EX05-1	12/04/97	18.0	2.3	ND	0.4	0.0015	0.0
EX05-2	12/04/97	19.0	0.8	ND	3.1	0.0015	0.0
EX05-3	12/04/97	20.0	86.0	ND	ND	0.0015	0.0
EX06-1	12/05/97	16.5	0.7	ND	0.5	0.0015	0.0
EX06-2	12/05/97	18.0	0.8	ND	ND	0.0015	0.0
EX06-3	12/05/97	19.0	0.5	ND	ND	0.0015	0.4
HC01-1	12/08/97	18.5	1540.0	ND	ND	0.0015	3.2
HC01-2	12/08/97	20.0	10489.0	ND	ND	0.0150	0.1
HC01-3	12/08/97	21.0	712.0	ND	ND	60.0000	4.1
IN01-1	12/08/97	18.0	13406.0	ND	ND	0.0015	4.6
IN01-2	12/08/97	19.5	15553.0	ND	ND	0.0060	0.2
IN01-3	12/08/97	20.5	708.0	ND	ND	0.0015	0.0
IN03-1	12/08/97	16.0	5.2	0.1	0.6	0.0015	0.0
IN03-2	12/08/97	17.5	2.7	ND	ND	0.0015	0.0
IN03-3	12/08/97	19.0	18.0	0.2	ND	0.0015	0.0
HC02-1	12/08/97	16.0	1.2	0.1	0.1	0.0015	0.0
HC02-2	12/09/97	17.0	9.4	0.1	ND	0.0015	0.0
HC02-3	12/09/97	18.5	25.0	0.2	ND	0.0015	0.0
RW03-2	12/09/97	21.6	287.0	1.7	ND	0.0015	0.04
RW04-1	12/09/97	18.0	25.0	0.1	ND	0.0015	0.0
RW04-2	12/09/97	19.5	23057.0	ND	ND	0.0015	7.1
RW04-3	12/09/97	20.5	448.0	ND	ND	0.0060	0.0

PCE - Tetrachloroethene  
 TCE - Trichloroethene  
 DCE - Dichloroethene  
 mg/kg - milligrams per kilogram  
 f<sub>oc</sub> - fraction organic carbon  
 NAPL - Non-aqueous phase liquid

**TABLE 1-4**  
**PRE -SEAR GROUNDWATER VOC CONCENTRATIONS**  
 OPERABLE UNIT NO. 15 - SITE 88  
 MCB CAMP LEJEUNE, NORTH CAROLINA

Sample ID	Sample Date	PCE (mg/L)	TCE (mg/L)	DCE (mg/L)
RW01	8/21/97	170.0	3.2	11.0
RW02	8/22/97	150.0	3.5	10.0

Note:

PCE - Tetrachloroethene  
 TCE - Trichloroethene  
 DCE - Dichloroethene  
 mg/L - milligrams per liter

**TABLE 1-5**  
**POST-SEAR SOIL BORING CONCENTRATIONS**  
 OPERABLE UNIT NO. 15 - SITE 88  
 MCB CAMP LEJEUNE, NORTH CAROLINA

Sample ID	Sample Depth (ft bgs)	f <sub>oc</sub>	PCE Concentration (mg/kg)	DNAPL Saturation (%)
IS35-2	17.0-17.5	0.0023	2.1	0.0
IS35-3	17.5-18.0	0.0023	2,533	0.7
IS35-4	18.0-18.5	0.0084	6,247	1.7
IS35-5	18.5-19.0	0.0084	11,129	3.2
IS35-6	19.0-19.5	0.0084	1,084	0.1
IS36-2	17.0-17.5	0.0023	3,088	0.9
IS36-3	17.5-18.0	0.0023	9,655	2.9
IS36-4	18.0-18.5	0.0084	3,887	1.0
IS36-5	18.5-19.0	0.0084	3,549	0.9
IS36-6	19.0-19.5	0.0084	485	0.0
IS38-3	17.0-17.5	0.0023	0.2	0.0
IS38-4	18.0-18.5	0.0084	ND	0.0
IS38-5	18.5-19.0	0.0084	1,471	0.3
IS38-6	19.0-19.5	0.0084	11,810	3.4
IS40-2	17.0-17.5	0.0023	ND	0.0
IS40-3	17.5-18.0	0.0023	ND	0.0
IS40-4	18.0-18.5	0.0023	ND	0.0
IS40-5	18.5-19.0	0.0084	144	0.0
IS40-6	19.0-19.5	0.0084	1,692	0.3
IS41-1	16.5-17.0	0.0023	ND	0.0
IS41-2	17.0-17.5	0.0023	ND	0.0
IS41-3	17.5-18.0	0.0023	ND	0.0
IS41-4	18.0-18.5	0.0084	30	0.0
IS41-5	18.5-19.0	0.0084	1.5	0.0
IS41-6	19.0-19.5	0.0084	0.5	0.0
IS44-2	17.0-17.5	0.0023	57	0.0
IS44-3	17.5-18.0	0.0023	9,759	2.9
IS44-4	18.0-18.5	0.0084	6,142	1.7
IS44-5	18.5-19.0	0.0084	8,754	2.5
IS44-6	19.0-19.5	0.0084	739	Trace
IS47-2	17.5-18.0	0.0023	8,279	2.5
IS47-3	18.0-18.5	0.0084	5,839	1.6
IS47-4	18.5-19.0	0.0084	5,587	1.5
IS47-5	19.0-19.5	0.0084	7,651	2.2
IS47-6	19.5-20.0	0.0084	7,536	2.1

PCE - Tetrachloroethene  
 foc - fraction organic carbon  
 mg/kg - milligrams per kilogram  
 DNAPL - Dense non-aqueous phase liquid



**TABLE 1-5**  
**POST-SEAR SOIL BORING CONCENTRATIONS**  
 OPERABLE UNIT NO. 15 - SITE 88  
 MCB CAMP LEJEUNE, NORTH CAROLINA

Sample ID	Sample Depth (ft bgs)	f <sub>oc</sub>	PCE Concentration (mg/kg)	DNAPL Saturation (%)
IS49-1	17.0-17.5	0.0023	2	0.0
IS49-2	17.5-18.0	0.0023	1	0.0
IS49-3	18.0-18.5	0.0084	6,144	1.7
IS49-4	18.5-19.0	0.0084	4,689	1.2
IS49-5	19.0-19.5	0.0084	17,198	5.1
IS49-6	19.5-20.0	0.0084	4,268	1.1
IS50-1	17.0-17.5	0.0023	ND	0.0
IS50-2	17.5-18.0	0.0230	ND	0.0
IS50-3	18.0-18.5	0.0084	3,159	0.8
IS50-4	18.5-19.0	0.0084	5,147	1.4
IS50-5	19.0-19.5	0.0084	7,382	2.1
IS50-6	19.5-20.0	0.0084	3,182	0.8
IS51-1	17.0-17.5	0.0023	ND	0.0
IS51-2	17.5-18.0	0.0023	20	0.0
IS51-3	18.0-18.5	0.0023	181	0.0
IS51-4	18.5-19.0	0.0084	2,930	0.7
IS51-5	19.0-19.5	0.0084	338	0.0
IS51-6	19.5-20.0	0.0084	85	0.0
IS52-2	17.5-18.0	0.0023	3,432	1.0
IS52-3	18.0-18.5	0.0084	5,997	1.6
IS52-4	18.5-19.0	0.0084	5,813	1.6
IS52-5	19.0-19.5	0.0084	3,926	1.0
IS55-2	17.5-18.0	0.0023	3,077	0.9
IS55-4	18.5-19.0	0.0084	5,134	1.4
IS55-5	19.0-19.	0.0084	1,847	0.4

Average by Column		Average by Depth	
Sample ID	PCE Concentration (mg/kg)	Depth (ft bgs.)	PCE Concentration (mg/kg)
IS35	4,199	17.0-17.5	350
IS36	4,133	17.5-18.0	3,341
IS38	3,320	18.0-18.5	3,421
IS40	367	18.5-19.0	4,529
IS41	5	19.0-19.5	4,513
IS44	5,090	19.5-20.0	3,768
IS47	6,978	Overall Average:	3,352
IS49	5,384		
IS50	3,145		
IS51	592		
IS52	4,792		
IS55	3,353		

PCE - Tetrachloroethene  
 foc - fraction organic carbon  
 mg/kg - milligrams per kilogram  
 DNAPL - Dense non-aqueous phase liquid

**TABLE 8-1**  
**Pre-Treatment and Post-Treatment Soil Gas Sampling Analytical Results**  
 Operable Unit No. 15 - Building 25  
 MCB Camp Lejeune, North Carolina

Station ID				IR88-SG01		IR88-SG02		IR88-SG03		IR88-SG04	
Sample ID				IR88-SG01-04D-5	IR88-SG01-05D-5	IR88-SG02-04D-5	IR88-SG02-05D-5	IR88-SG03-04D-5	IR88-SG03-05D-5	IR88-SG04-04D-5	IR88-SG04-05D-5
Sample Date				12/27/04	9/29/05	12/27/04	9/29/05	12/27/04	9/29/05	12/27/04	9/29/05
Chemical Name	Frequency	Max Value	Max Location								
Volatile Organic Compounds (µg/m³)											
1,2,4-TRIMETHYLBENZENE	4 / 8	2,600	IR88-SG02-05D-5	1,300 U	320	410	2,600	160 U	10000 U	53 U	340
1,3,5-TRIMETHYLBENZENE	4 / 8	2,000	IR88-SG02-05D-5	1,300 U	260	250	2,000	160 U	10000 U	53 U	210
2-PROPANOL	4 / 8	19,000	IR88-SG03-05D-5	650 U	2,100	83 U	2,700	80 U	19,000	26 U	45
BENZENE	3 / 8	1,000	IR88-SG02-05D-5	850 U	140	110 U	1,000	100 U	6700 U	34 U	42
CHLOROBENZENE	1 / 8	70.0	IR88-SG02-05D-5	1,200 U	48 U	150 U	70	150 U	9600 U	50 U	48 U
CIS-1,2-DICHLOROETHENE	5 / 8	5,100,000	IR88-SG03-05D-5	1,000 U	120	5,100	640	130 U	5,100,000	43 U	13,000
ETHYL BENZENE	1 / 8	96.0	IR88-SG02-05D-5	1,200 U	45 U	150 U	96	140 U	9100 U	47 U	45 U
M,P-XYLENE	1 / 8	210.0	IR88-SG02-05D-5	1,200 U	45 U	150 U	210	140 U	9100 U	47 U	45 U
METHYLENE CHLORIDE	1 / 8	45,000	IR88-SG03-05D-5	920 U	36 U	120 U	36 U	110 U	45,000	38 U	36 U
O-XYLENE	1 / 8	190.0	IR88-SG02-05D-5	1,200 U	45 U	150 U	190	140 U	9100 U	47 U	45 U
TETRACHLOROETHENE	7 / 8	1,400,000	IR88-SG01-04D-5	1,400,000	490	10,000	1,700	130,000	14000 U	3200	160
TOLUENE	2 / 8	340.0	IR88-SG02-05D-5	1,000 U	97	130 U	340	120 U	7900 U	41 U	39 U
TRANS-1,2-DICHLOROETHENE	1 / 8	18,000	IR88-SG03-05D-5	1,000 U	41 U	130 U	41 U	130 U	18,000	43 U	41 U
TRICHLOROETHENE	3 / 8	4,500	IR88-SG01-04D-5	4,500	56 U	180 U	170	840	11000 U	58 U	56 U
VINYL CHLORIDE	6 / 8	680,000	IR88-SG03-05D-5	680 U	27 U	57,000	260	160	680,000	42	1,600

Notes:  
 Shaded cells represent detections  
 U - Not detected



TABLE 8-2  
Post-Treatment Soil Analytical Results  
Operable Unit No. 15 - Building 25  
MCB Camp Lejeune, North Carolina

FEBRUARY 2005																			
Sample ID	1	2	3	4	5	6	7	13	14	11	12	15	16	17	21	22	23	24	25
Sample Date	2/15/2005	2/15/2005	2/15/2005	2/15/2005	2/15/2005	2/15/2005	2/15/2005	2/21/2005	2/21/2005	2/22/2005	2/22/2005	2/23/2005	2/24/2005	2/24/2005	2/26/2005	2/26/2005	2/28/2005	2/28/2005	2/25/2005
Sample Loc. (Column #)	5	5	36	36	36	13	13	115	115	106	106	123	125	125	146	146	16	16	143
Sample Depth (ft bgs)	15	5	15	5	5	15	5	5	15	5	15	5	5	15	5	15	5	15	15
Chemical Name																			
DCE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TCE	8,800	11,600	8,300	6,600	6,700	8,800	12,700	8,000	12,300	13,300	12,100	10,900	12,500	13,100	8,300	6,200	19,900	34,900	15,900
PCE	2,052,000	2,722,000	1,460,000	982,000	956,000	1,514,000	1,930,000	420,000	552,000	906,000	670,000	440,000	632,000	651,000	1,611,000	774,000	227,000	90,000	2,247,000

APRIL 2005				
Sample ID	IR88-IS07-05B-5-6	IR88-IS07-05B-9-10	IR88-IS08-05B-5-6	IR88-IS08-05B-9-10
Sample Date	4/26/2005	4/26/2005	4/26/2005	4/26/2005
Sample Loc. (Column #)	13	13	143	143
Sample Depth (ft bgs)	5	10	5	10
Chemical Name				
DCE	24,000	8,400	21,000	33,000
TCE	14,000	16,000	85,000	570
PCE	730,000	340,000	800,000	600

AUGUST 2005										
Sample ID	IR88-IS100-10	IR88-IS100-20	IR88-IS101-15	IR88-IS101-5	IR88-IS106-10	IR88-IS106-20	IR88-IS107-5	IR88-IS107-15	IR88-IS108-10	IR88-IS108-20
Sample Date	8/3/2005	8/4/2005	8/3/2005	8/3/2005	8/5/2005	8/4/2005	8/4/2005	8/4/2005	8/4/2005	8/4/2005
Sample Loc. (Column #)	36	36	13	13	115	115	125	125	143	143
Sample Depth (ft bgs)	10	20	15	5	10	20	5	15	10	20
Chemical Name										
DCE	250	1,700	270	7	9,200	4,400	57	37,000	19,000	6,600
TCE	5	7	350	19	370	2,900	280	8,700	8,500	95,000
PCE	200	55	350	180	370	83,000	280	51,000	43,000	3,800,000

OCTOBER 2005																				
Sample ID	IR88-MW30-05	IR88-MW30-10	IR88-MW30-15	IR88-MW30-20	IR88-MW31-05	IR88-MW31-10	IR88-MW31-15	IR88-MW31-20	IR88SSIS301-5	IR88SSIS301-10	IR88SSIS301-15	IR88SSIS301-20	IR88SSIS302-5	IR88SSIS302-10	IR88SSIS302-15	IR88SSIS302-20	IR88SSIS303-5	IR88SSIS303-10	IR88SSIS303-15	IR88SSIS303-20
Sample Date	10/13/2005	10/13/2005	10/13/2005	10/13/2005	10/13/2005	10/13/2005	10/13/2005	10/13/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005	10/19/2005
Sample Loc. (Column #)	60	60	60	60	134	134	134	134	143	143	143	143	76	76	76	76	60	60	60	60
Sample Depth (ft bgs)	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20
Chemical Name																				
DCE	61	580	200	190	970	35,000	210,000	3,000	1,100	530	43	320	300	3,500	5,700	3,600	67	520	900	5
TCE	54	55	18	11	1,200	88,000	110,000	11,000	270	220	95	670	300	260	250	280	310	2	280	9
PCE	270	180	220	170	6,800	650,000	4,000,000	310,000	1,000	17,000	15,000	26,000	300	260	250	280	310	100	280	9
VC															210					

FEBRUARY 2006																					
Sample ID	IR88-IS304-10	IR88-IS304-15	IR88-IS304-20	IR88-IS305-10	IR88-IS305-15	IR88-IS305-20	IR88-IS306-10	IR88-IS306-15	IR88-IS306-20	IR88-IS307-10	IR88-IS307-15	IR88-IS307-20	IR88-IS308-10	IR88-IS308-15	IR88-IS308-20	IR88-IS309-10	IR88-IS309-15	IR88-IS309-20	IR88-IS310-10	IR88-IS310-15	IR88-IS310-20
Sample Date	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006	2/17/2006
Sample Loc. (Column #)	143	143	143	134	134	134	125	125	125	115	115	115	60	60	60	36	36	36	13	13	13
Sample Depth (ft bgs)	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20
Chemical Name																					
DCE																					
TCE	15,500	67,640	52,630	120	10,420	51,310	1,930	760	57,110	60	60	55	50	70	60	75	60	50	10	60	40
PCE	14,660	550,180	1,377,200	810	479,000	884,520	10,100	26,690	1,322,910	190	230	220	270	310	280	400	330	320	750	520	380

Note:  
All concentrations are in micrograms per kilogram  
Shaded samples represent DNAPL (source) areas



TABLE 8-3  
Baseline Groundwater Monitoring Detections - Intermediate Monitoring Wells  
Operable Unit No. 15 - Building 25  
MCB Camp Lejeune, North Carolina

	Sample Date	88-MW01		88-MW02		88-MW03		88-MW04		88-MW05		RW-02	EX-04
		IR88-GW01-02C	IR88-GW01-03C	IR88-GW02-02C	IR88-GW02-03C	IR88-GW03-02C	IR88-GW03-03C	IR88-GW04-02C	IR88-GW04-03C	IR88-GW05-02C	IR88-GW05-03C	IR88-GWSRW02-04B	IR88-GWSEX04-04B
		7/23/2002	10/1/2003	7/26/2002	10/5/2003	7/25/2002	10/7/2003	7/23/2002	10/5/2003	7/25/2002	10/6/2003	4/16/2004	4/16/2004
Chemical Name	NCGQWS												
Volatile Organic Compounds (µg/L)													
1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	210,000	10 U		10 U	NA	10 U	NA	10 U		10 U		NA	NA
1,1-DICHLOROETHENE	7	10 U	1 U	10 U	1 U	10 U	0.6 J	10 U	1 U	50	1 U	1300 U	420 U
1,2-DICHLOROETHYLENE (TOTAL)	NS	NA	2 U	NA	2 U	NA	4	NA	2 U	NA	29	39,000	5,300
4-METHYL-2-PENTANONE	NS	10 U		10 U	NA	10 U	NA	10 U		10 U		2200 U	430 U
ACETONE	700	10 U	5 U	10 U	5 U	10 U	5 U	10 U	5 U	14 U	5 U	140,000	630 U
BENZENE	1	10 U	1 U	10 U	1 U	10 U	1 U	10 U	1 U	57	1 U	860 U	170 U
CARBON DISULFIDE	700	10 U	1 U	10 U	1 U	10 U	1 U	10 U	1 U	10 U	1 U	NA	NA
CHLOROBENZENE	50	10 U		10 U	NA	10 U	NA	10 U		60		500 U	100 U
CHLOROMETHANE	2.6	10 U	2 U	10 U	2 U	10 U	2 U	10 U	2 U	10 U	2 U	620 U	120 U
CIS-1,2-DICHLOROETHENE	70	10 U	1 U	10 U	1	1 U	4	10 U	1 U	40	28	39,000	5,300
ETHENE	NS	2 U		2 U	NA	2 U	NA	2 U		2 U		NA	NA
ETHYLBENZENE	29	10 U		10 U	NA	10 U	NA	10 U		10 U		720 U	140 U
ISOPROPANOL	NS	4 U		6 U	NA	6 U	NA	4 U		4 U		NA	NA
ISOPROPYLBENZENE	70	10 U		10 U	NA	10 U	NA	10 U		10 U		780 U	160 U
METHANE	NS	1 U		0.3 U	NA	12	NA	0.3 U		0.6 U		NA	NA
TETRACHLOROETHENE	0.7	10 U	1 U	45	16	2 U	13 U	10 U	1 U	2,300	800	64,000	52,000
TOLUENE	1,000	1 U	1 U	10 U	0.3 J	0.5 U	1 U	0.7 U	0.2 J	58	1 U	1000 U	200 U
TRANS-1,2-DICHLOROETHENE	70	10 U	1 U	10 U	1 U	10 U	1 U	10 U	1 U	0.4 J	0.9 J	1400 U	280 U
TRICHLOROETHENE	2.8	10 U	1 U	1 J	4	1 J	2	10 U	1 U	95	29	37,000	2,300
VINYL CHLORIDE	0.015	10 U	2 U	10 U	0.8 J	10 U	2 U	10 U	2 U	10 U	2 U	15,000	120 U
XYLENE (TOTAL)	530	10 U	3 U	10 U	3 U	10 U	3 U	10 U	3 U	10 U	3 U	690 U	140 U
Total Metals (UG/L)													
ALUMINUM	NS	1,200	802	326	272 U	78.8 U	111 U	499	811	487	106 U	270	440
ARSENIC	10	2.5 U	3.5 J	1.3 U	2.13 U	1.3 U	2.13 U	2.5 U	2.13 U	2.5 U	2.13 U	13	5 U
BARIUM	2,000	45.2 J	45.7	15.6 J	11.9	56.8 J	62.4	35.5 J	22.7	26.7 J	26.1	27	130
CALCIUM	NS	14,400	26,400	22,700	19,800	4,190 J	1,800	5,090	5,590	8,130	10,700	55,000	16,000
CHROMIUM	50	0.4 U	1.2 U	1.5 U	0.88 U	0.7 U	0.88 U	0.4 U	1.2 J	1 U	0.88 U	NA	7.6
IRON	300	12,200	12,200	117	207	1,350	1,910	9.5 U	163	322	25.4 U	6,200	3,300
MAGNESIUM	NS	5,140	5,580	796 J	442	1,580 J	1,880	3,310 J	2,740	476 U	478	1,600	2,000
MANGANESE	50	41.5 J	46.2	3.1 U	2.5 J	18.4	21.7	2.8 U	2.4 J	7.2 J	7.6	50	31
MERCURY	1.1	0.1 U	0.14 J	0.1 U	0.09 J	0.1 U	0.13 J	0.1 U	0.08 J	0.1 U	0.13 J	NA	NA
POTASSIUM	NS	2,770 J	3,340	1,340 J	542 J	1,220 J	1,260	823 J	1,150	1,680 J	2,390	8,400	1,700
SELENIUM	50	1.7 U	2.32 U	2.9 U	2.32 U	2.9 U	2.32 U	1.7 U	2.32 U	1.7 U	2.32 U	5.7	1 U
SODIUM	NS	11,300	23,200	9,780	5,720	5,340	5,030	4,800 J	7,630	2,730 J	3,830	30,000	9,700
THALLIUM	NS	4.2 U	2.77 U	2.6 U	5.9 J	2.6 U	6.8 J	4.2 U	2.77 U	4.2 U	2.77 U	10 U	10 U
VANADIUM	NS	2.9 U	2.6 J	2.2 U	1.4 U	1.4 U	1.1 U	0.7 U	1.2 J	1.1 U	0.74 U	5 U	7.3
ZINC	2,100	29.9	23.6 J	12.4 U	3 U	3.6 U	1.1 U	1.8 U	0.73 U	3.3 U	1.2 U	48	77
Wet Chemistry (MG/L)													
CHLORIDE	250	25.1	26	9.42	5.7	4.61	8.1	9.98	13	6.26	6	150	28
FERROUS IRON	0.3	10.5		0.1 U		0.79		0.1 U		0.1 U		NA	NA
METHANE	NS	1 U	900	0.3 U	10 U	12	210	0.3 U	10 U	0.6 U	10 U	NA	NA
NITRATE	10	0.05 U	0.05 U	0.05 U	0.93	0.05 U	0.05 U	0.05 U	0.083	0.07	0.8	0.011	0.4
SULFATE	250	73.8	110	11.5	7.7	15.2	18	43.6	27	15.9	20	NA	NA
SULFIDE	NS	0.5 U	2.2	0.6 U	1 U	0.5 U	1 U	0.56	1 U	0.5 U	1 U	NA	NA
TOTAL ORGANIC CARBON	NS	5 U	3.4	5 U	1 U	5 U	1 U	5 U	1 U	5 U	1 U	NA	NA

Note: Grey highlight means contaminant detected  
NA - Not Analyzed  
U - Analyte Not Detected  
J - Reported Value is Estimated  
D - Result came from a Diluted Sample



TABLE 8-3  
Baseline Groundwater Monitoring Detections - Intermediate Monitoring Wells  
Operable Unit No. 15 - Building 25  
MCB Camp Lejeune, North Carolina

	Sample Date	88-MW02IW			88-MW03IW		88-MW05IW		88-MW06IW	88-MW10IW	
		IR88-GW02IW-02C	IR88-GW02IW-03C	IR88-GW02IWD-03C	IR88-GW03IW-02C	IR88-GW03IW-03C	IR88-GW05IW-02C	IR88-GW05IW-03C	IR88-GW06IW-03C	IR88-GW10IW-02C	IR88-GW10IW-03C
		7/26/2002	10/5/2003	10/5/2003	7/25/2002	10/7/2003	7/25/2002	10/6/2003	10/3/2003	7/25/2002	10/5/2003
Chemical Name	NCGQWS										
<b>Volatile Organic Compounds (µg/L)</b>											
1,1-DICHLOROETHANE	700	10 U	1 U	1 U	10 U	1 U	0.6 J	0.7 J	1 U	10 U	1 U
1,1-DICHLOROETHENE	7	10 U	0.5 J	0.3 J	0.5 J	0.8 J	9 J	9	1 U	10 U	1 U
1,2-DICHLOROETHYLENE (TOTAL)	NS	NA	39	40	NA	21	NA	1,600	2 U		13
ACETONE	700	10 U	5 U	5 U	5 U	5 U	9 U	5 U	5 U	10 UJ	5 U
BENZENE	1	10 U	1 U	1 U	10 U	1 U	10 U	0.2 J	1 U	10 U	1 U
CARBON DISULFIDE	0.19	10 U	1 U	1 U	10 U	1 U	10 U	1 U	1 U	10 UJ	1 U
CHLOROFORM	50	10 U	1 U	1 U	10 U	1 U	10 U	1 U	1 U	10 U	1 U
CHLOROMETHANE	3	10 U	2 U	2 U	10 U	2 U	10 U	2 U	2 U	10 U	2 U
CIS-1,2-DICHLOROETHENE	70	60	38	39	22 U	20	2,200 D	1,600	1 U	4 U	13
m- and p- XYLENES	530	NA	2 U	2 U	NA	0.1 J	NA	2 U	2 U	NA	2 U
O-XYLENE	530	NA	1 U	1 U	NA	1 U	NA	0.3 J	1 U	NA	1 U
STYRENE	100	10 U	1 U	1 U	10 U	1 U	10 U	1 U	1 U	10 U	1 U
TETRACHLOROETHENE	0.7	2,700 D	2,600	2,000	1,900 D	1,200	3,400 D	1,900	1 U	1 U	76
TOLUENE	1000	0.8 U	0.4 J	1 U	0.5 U	0.6 J	0.8 U	0.3 J	0.2 J	1 U	0.5 J
TRANS-1,2-DICHLOROETHENE	70	2 J	1	1	0.8 J	1	19	28	1 U	10 U	1 U
TRANS-1,3-DICHLOROPROPENE	NS	10 U	1 U	1 U	10 U	1 U	10 U	1 U	1 U	10 U	1 U
TRICHLOROETHENE	2.8	410 D	230	210	410 D	280	2,300 D	1,800	1 U	2 J	31
VINYL CHLORIDE	0.015	10 U	2 U	2 U	10 U	2 U	1 J	1 J	2 U	10 U	2 U
XYLENE (TOTAL)	530	10 U	3 U	3 U	10 U	3 U	10 U	3 U	3 U	10 U	3 U
<b>Total Metals (UG/L)</b>											
ALUMINUM	NS	684	371 U	366 U	84.2 U	36.9 U	108 U	128 U	237 J	201	104 U
ANTIMONY	NS	1.6 U	2.8 J	1.8 J	1.6 U	1.74 U	1.6 U	2.8 J	1.74 U	1.9 U	2 J
ARSENIC	10	1.7 U	2.13 U	2.13 U	2.6 U	3.3 J	1.3 U	2.13 U	2.13 U	1.3 U	2.13 U
BARIUM	2,000	77 J	224	206	244 J	27.7	30.9 J	47.1	76.2	13.9 J	11.9
BERYLLIUM	NS	0.82 U	0.22 U	0.22 U	0.34 U	0.22 U	0.42 U	0.22 U	0.32 U	0.38 U	0.22 U
CADMIUM	5	0.68 U	3 J	2.2 J	0.2 U	0.25 U	0.2 U	0.25 U	0.25 U	0.2 U	0.25 U
CALCIUM	NS	29,500	87,100	79,800	101,000	94,200	98,500	96,200	21,200	8,400	7,650
CHROMIUM	50	2.9 U	0.88 U	0.88 U	1.5 U	0.88 U	0.76 U	0.88 U	1.1 J	1.8 U	0.88 U
COBALT	NS	0.4 U	0.58 U	0.58 U	0.4 U	0.58 U	0.59 U	0.58 U	0.58 U	0.4 U	0.58 U
COPPER	1000	0.6 U	1.14 U	1.14 U	0.6 U	1.14 U	0.6 U	1.14 U	1.14 U	0.6 U	1.14 U
IRON	300	424	325	372	3,380	3,160	795	879	34.8 J	1,830	1,600
LEAD	15	1.6 U	1.56 U	1.56 U	0.82 U	1.56 U	0.7 U	1.56 U	1.56 U	0.7 U	1.56 U
MAGNESIUM	NS	941 J	633	673	2,950 J	3,050	4,510 J	3,930	2,200	1,020 J	807
MANGANESE	50	11.9 J	11.9	13.3	39.6	33.1	29.9	27.6	8.7	30.7	28.6
MERCURY	1.1	0.1 U	0.04 U	0.06 U	0.1 U	0.12 J	0.1 U	0.13 J	0.05 J	0.1 U	0.05 J
NICKEL	100	3 U	8 J	7.1 J	0.92 U	0.95 U	1.4 U	1 J	0.95 U	1.1 U	1 J
POTASSIUM	NS	2,960 J	2,650	2,810	1,560 J	1,620	2,040 J	1,760	2,640	2,120 J	2,910
SELENIUM	50	2.9 U	2.32 U	2.32 U	2.9 U	2.32 U	2.9 U	2.32 U	2.8 J	2.9 U	2.32 U
SODIUM	NS	11,800	7,470	7,750	7,170	6,070	7,540	7,030	9,170	10,600	8,250
THALLIUM	NS	2.6 U	2.77 U	5.5 U	2.6 U	2.77 U	2.6 U	3.3 J	3 J	2.6 U	9 J
VANADIUM	NS	2.6 U	1.8 U	2.1 U	0.48 U	0.74 U	1 U	0.74 U	0.74 U	1.1 U	0.74 U
ZINC	2,100	146	148	120	0.7 U	0.54 U	52.1	4.4 J	1.7 U	0.7 U	11 J
<b>Wet Chemistry (MG/L)</b>											
CHLORIDE	250	6.06	8.2	8.4	5.77	6	12.7	14.0	14.0	7.12	7.2
ETHANE	NS	8 U	10 U	10 U	2 U	10 U	0.04	10 U	10 U	150 U	10 U
METHANE	NS	55	460	470	20	150	12 J	110	10 U	590	8,600
NITRATE	10	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	4	0.05 U	0.05 U
NITRITE	1	NA	0.057	0.082	NA	0.05 U	NA	0.05 U	0.05 U	NA	0.05 U
SULFATE	250	10.4	14	15	25.2	20	22.6	22.0	12.0	5 U	3.6
SULFIDE	NS	0.58 U	1 U	1 U	0.5 U	1.9	0.5 U	1 U	1 U	0.68 U	1 U
TOTAL ORGANIC CARBON	NS	5.61	3.4	3.6	5 U	1 U	5 U	1.1	1.1	5.87	4.1

Note: Grey highlight means contaminant detected  
NA - Not Analyzed  
U - Analyte Not Detected  
J - Reported Value is Estimated  
D - Result came from a Diluted Sample



TABLE 8-3  
Baseline Groundwater Monitoring Detections - Intermediate Monitoring Wells  
Operable Unit No. 15 - Building 25  
MCB Camp Lejeune, North Carolina

	Sample Date	88-MW02DW			88-MW03DW		88-MW05DW	
		IR88-GW02DW-02C	IR88-GW02DW-P-02C	IR88-GW02DW-03C	IR88-GW03DW-02C	IR88-GW03DW-03C	IR88-GW05DW-P-02C	IR88-GW05DW-03C
		7/24/2002	7/24/2002	10/5/2003	7/26/2002	10/7/2003	7/24/2002	10/6/2003
Chemical Name	NCGQWS							
Volatile Organic Compounds (µg/L)								
1,1-DICHLOROETHANE	700	10 U	10 U	1 U	10 U	1 U	10 U	1 U
1,1-DICHLOROETHENE	7	10 U	10 U	1 U	10 U	1 U	10 U	0.4 J
1,2-DICHLOROETHYLENE (TOTAL)	NS	NA	NA	30	NA	2 U	NA	31
ACETONE	700	4 U	4 U	3 J	10 UJ	5 U	4 U	5 U
BENZENE	1	10 U	10 U	1 U	10 U	1 U	10 U	1 U
CARBON DISULFIDE	700	10 U	10 U	0.5 J	10 U	1 U	10 U	1 U
CHLOROFORM	0.19	10 U	10 U	1 U	10 U	1 U	10 U	1 U
CHLOROMETHANE	2.6	10 U	10 U	2 U	10 U	2 U	10 U	2 U
CIS-1,2-DICHLOROETHENE	70	34 U	36 U	30	10 U	1 U	15	29
m- and p- XYLENES	530	NA	NA	2 U	NA	2 U	NA	2 U
O-XYLENE	530	NA	NA	1 U	NA	1 U	NA	1 U
STYRENE	100	10 U	10 U	1 U	10 U	1 U	10 U	1 U
TETRACHLOROETHENE	0.7	23	24	190	10 U	1 U	390	300
TOLUENE	1,000	0.7 U	0.6 U	0.4 J	10 U	1 U	0.8 U	0.3 J
TRANS-1,2-DICHLOROETHENE	70	0.5 J	0.4 J	1 U	10 U	1 U	0.8 J	2
TRANS-1,3-DICHLOROPROPENE	NS	10 U	10 U	1 U	10 U	1 U	10 U	1 U
TRICHLOROETHENE	2.8	2 J	2 J	13	10 U	1 U	120	100
VINYL CHLORIDE	0.015	0.5 J	10 U	2 U	10 U	2 U	10 U	2 U
XYLENE (TOTAL)	530	10 U	10 U	3 U	10 U	3 U	10 U	3 U
Total Metals (UG/L)								
ALUMINUM	NS	57.7 U	63.4 U	66 U	1,540	1,750	119 U	104 U
ANTIMONY	NS	3.1 U	2.1 U	1.74 U	1.6 U	3.1 J	1.7 U	2.2 J
ARSENIC	10	1.3 U	1.3 U	2.13 U	1.3 U	2.13 U	2.5 U	2.13 U
BARIUM	2,000	65.9 J	55.7 J	271	25 J	20	30.1 J	25.8
BERYLLIUM	NS	0.2 U	0.47 U	0.22 U	0.32 U	0.22 U	0.2 U	0.22 U
CADMIUM	5	0.23 U	0.2 U	0.25 U	0.2 U	0.25 U	0.4 U	0.25 U
CALCIUM	NS	76,400	77,500	96,600	98,500	107,000	72,300	76,400
CHROMIUM	50	1.5 U	1.3 U	0.88 U	0.76 U	1 J	0.4 U	0.88 U
COBALT	NS	1.4 U	0.68 U	0.58 U	0.4 U	0.58 U	0.4 U	0.69 J
COPPER	1000	2.5 U	0.6 U	1.14 U	0.6 U	1.14 U	0.8 U	1.14 U
IRON	300	522	538	151	31.9 U	13.9 U	868	908
LEAD	15	0.7 U	0.7 U	1.56 U	0.97 U	1.56 U	1.3 U	1.56 U
MAGNESIUM	NS	2,610 J	2,650 J	1,090	461 U	33.9 J	2,350 J	2,620
MANGANESE	50	10.9 J	10.7 J	3.4 J	1.3 U	0.7 J	15 J	16.5
MERCURY	1.1	0.11 J	0.1 U	0.09 J	0.1 U	0.12 J	0.1 U	0.09 J
NICKEL	100	2.4 U	1 U	6.2 J	1 U	1.4 J	0.6 U	0.95 U
POTASSIUM	NS	1,590 J	1,580 J	1,650	3,620 J	4,790	9,520	6,460
SELENIUM	50	2.9 U	2.9 U	2.32 U	2.9 U	2.32 U	1.7 U	2.32 U
SODIUM	NS	22,200	21,800	16,800	15,800	8,200	15,500	15,800
THALLIUM	NS	2.6 U	2.6 U	2.77 U	2.6 U	3.3 J	4.2 U	3.4 J
VANADIUM	NS	1.7 U	0.84 U	0.74 U	6 J	5.1 J	0.53 U	1.2 U
ZINC	2,100	0.7 U	0.7 U	13.2 J	0.7 U	5.3 J	1.8 U	1.7 U
Wet Chemistry (MG/L)								
CHLORIDE	250	8.98	8.76	8.6	6.74	9.7	6.69	6.7
ETHANE	NS	2 U	2 U	10 U	15	94	2 U	10 U
METHANE	NS	7	7	720	59	560	0.3 U	10 U
NITRATE	10	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
NITRITE	1	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U		0.05 U
SULFATE	250	30.7	30.4	22	20.5	14	28.2	21
SULFIDE	NS	0.5 U	0.6 U	1 U	0.7 U	1 U	0.5 U	4.8
TOTAL ORGANIC CARBON	NS	5 U	5 U	6.2	5 U	1.6	5 U	1 U

Note: Grey highlight means contaminant detected  
NA - Not Analyzed  
U - Analyte Not Detected  
J - Reported Value is Estimated  
D - Result came from a Diluted Sample



TABLE 8-4  
Post-Treatment Groundwater Analytical R  
Operable Unit No. 15 - Building 25  
MCB Camp Lejeune, North Carolina

Station ID	NC2LGW	IR88-MW25					IR88-MW26				
Sample ID		IR88-GW25-05A	IR88-MW25-05B	IR88-MW25-05C	IR88-MW25-05D	IR88-MW25-06A	IR88-MW26-05A	IR88-MW26-05B	IR88-MW26-05C	IR88-MW26-05D	IR88-GW26-06A
Sample Date		01/03/05	06/02/05	08/31/05	11/15/05	02/22/06	01/03/05	06/02/05	08/31/05	11/15/05	02/22/06
Chemical Name											
Volatile Organic Compounds (UG/L)											
Acetone	700	500 U	1,000 U	1,000 U	1,000 U	1,000 U	67 U	67 U	140 U	140 U	140 U
Methylene chloride	4.6	500 U	1,000 U	120 J	1,000 U	1,000 U	67 U	67 U	16 J	140 U	140 U
Tetrachloroethene	0.7	12,000	11,000	8,300	9,800	8,200	680	1,400	1,900	1,700	1,200
Trichloroethene	2.8	500 U	1,000 U	1,000 U	1,000 U	1,000 U	10 J	11 J	14 J	140 U	140 U
Vinyl chloride	0.015	500 U	1,000 U	1,000 U	1,000 U	1,000 U	67 U	67 U	140 U	140 U	140 U
cis-1,2-Dichloroethene	70	500 U	1,000 U	1,000 U	1,000 U	1,000 U	21 J	14 J	140 U	140 U	27 J
trans-1,2-Dichloroethene	100	500 U	1,000 U	1,000 U	1,000 U	1,000 U	67 U	67 U	140 U	140 U	140 U

Station ID	NC2LGW	IR88-MW27							IR88-MW28						
Sample ID		IR88-GW27-05A	IR88-GW27-05A2	IR88-GW27-05A3	IR88-MW27-05B	IR88-GW27-05C	IR88-MW27-05D	IR88-GW-MW27-06	IR88-GW28-05A	IR88-GW28-05A2	IR88-GW28-05A3	IR88-MW28-05B	IR88-GW28-05C	IR88-MW28-05D	IR88-MW28-06A
Sample Date		01/03/05	02/19/05	02/23/05	06/03/05	08/31/05	11/15/05	02/22/06	01/03/05	02/19/05	02/23/05	06/02/05	08/31/05	11/15/05	02/22/06
Chemical Name															
Volatile Organic Compounds (UG/L)															
Acetone	700	120,000	150,000	130,000	86,000	81,000	46,000	19,000	1,400 U	1,400 U	2,500 U	2,500 U	2,500 U	1,000 U	1,000 U
Methylene chloride	4.6	25,000 U	25,000 U	10,000 U	7,100 U	7,100 U	7100 U	2,500 U	1,400 U	1,400 U	2,500 U	2,500 U	2,500 U	1,000 U	1,000 U
Tetrachloroethene	0.7	25,000 U	20,000 J	24,000	7,100 U	7,100 U	7100 U	2,500 U	22,000	28,000	47,000	20,000	16,000	9,100	7,300
Trichloroethene	2.8	25,000 U	4,400 J	6,300 J	1,400 J	1,000 J	970 J	380 J	1,100 J	1,000 J	1,600 J	1,100 J	790 J	490 J	400 J
Vinyl chloride	0.015	25,000 U	25,000 U	10,000 U	7,100 U	7,100 U	7100 U	2,500 U	1,400 U	1,400 U	2,500 U	2,500 U	2,500 U	1,000 U	1,000 U
cis-1,2-Dichloroethene	70	19,000 J	17,000 J	22,000	27,000	27,000	30,000	27,000	550 J	530 J	790 J	630 J	570 J	1,100	950 J
trans-1,2-Dichloroethene	100	25,000 U	13,000 J	10,000 U	7,100 U	7,100 U	7100 U	270 J	1,400 U	410 J	2,500 U	2,500 U	2,500 U	1,000 U	1,000 U

Station ID	NC2LGW	IR88-MW29					IR88-MW30		IR88-MW30IW		IR88-MW31		IR88-MW31IW	
Sample ID		IR88-GW29-05A	IR88-GW29-05A2	IR88-GW29-05A3	IR88-MW29-05B	IR88-GW29-05C	IR88-MW30-05D	IR88-MW30-06A	IR88-MW30IW-05D	IR88-MW30IW-06A	IR88-MW31-05D	IR88-MW31-06A	IR88-MW31IW-05D	IR88-MW31IW-06A
Sample Date		01/03/05	02/19/05	02/23/05	06/03/05	08/31/05	11/15/05	02/22/06	11/15/05	02/22/06	11/15/05	02/22/06	11/15/05	02/22/06
Chemical Name														
Volatile Organic Compounds (UG/L)														
Acetone	700	120,000	130,000	170,000	130,000	120,000	460	110 J	500 U	500 U	5,000 J	24,000 J	71 U	71 U
Methylene chloride	4.6	5,000 U	8,300 U	10,000 U	10,000 U	10,000 U	200 U	200 U	64 J	500 U	1,100 J	50,000 U	71 U	71 U
Tetrachloroethene	0.7	41,000	39,000	38,000	33,000	42,000	200 U	200 U	3,300	1,900	120,000	15,000 J	560	500
Trichloroethene	2.8	13,000	12,000	12,000	22,000	41,000	200 U	200 U	5,800	3,900	19,000	50,000 U	150	73
Vinyl chloride	0.015	5,000 U	8,300 U	10,000 U	10,000 U	10,000 U	69 J	92 J	500 U	350 J	10,000 U	50,000 U	71 U	71 U
cis-1,2-Dichloroethene	70	42,000	41,000	38,000	41,000	42,000	1,500	1,600	2,200	5,700	140,000	390,000	23 J	280
trans-1,2-Dichloroethene	100	5,000 U	8,300 U	10,000 U	10,000 U	10,000 U	200 U	200 U	500 U	500 U	10,000 U	10,000 U	71 U	71 U

Notes:  
Shaded cells represent exceedances  
J - Analyte present, result is estimated  
U - Not detected

TABLE 8-5

## Geoprobe Groundwater Analytical Results

Operable Unit No. 15 - Site 88

MCB Camp Lejeune, North Carolina

Station ID	NC2LGW	IR88-IS100	IR88-IS106	IR88-IS108
Sample ID		IR88-IS100-05C	IR88-IS106-17-19-05C	IR88-IS108-16-18-05C
Sample Date		08/03/05	08/04/05	08/04/05
Chemical Name				
<b>Volatile Organic Compounds (UG/L)</b>				
Acetone	700	6,800	43,000	7,300 J
Methylene chloride	4.6	2 J	5 J	17,000 U
Tetrachloroethene	0.7	1,500	11,000	160,000
Trichloroethene	2.8	1,800	9,000	6,500 J
Vinyl chloride	0.015	330 J	1,000 J	17,000 U
cis-1,2-Dichloroethene	70	19,000	250,000	27,000
trans-1,2-Dichloroethene	100	16	260 J	17,000 U

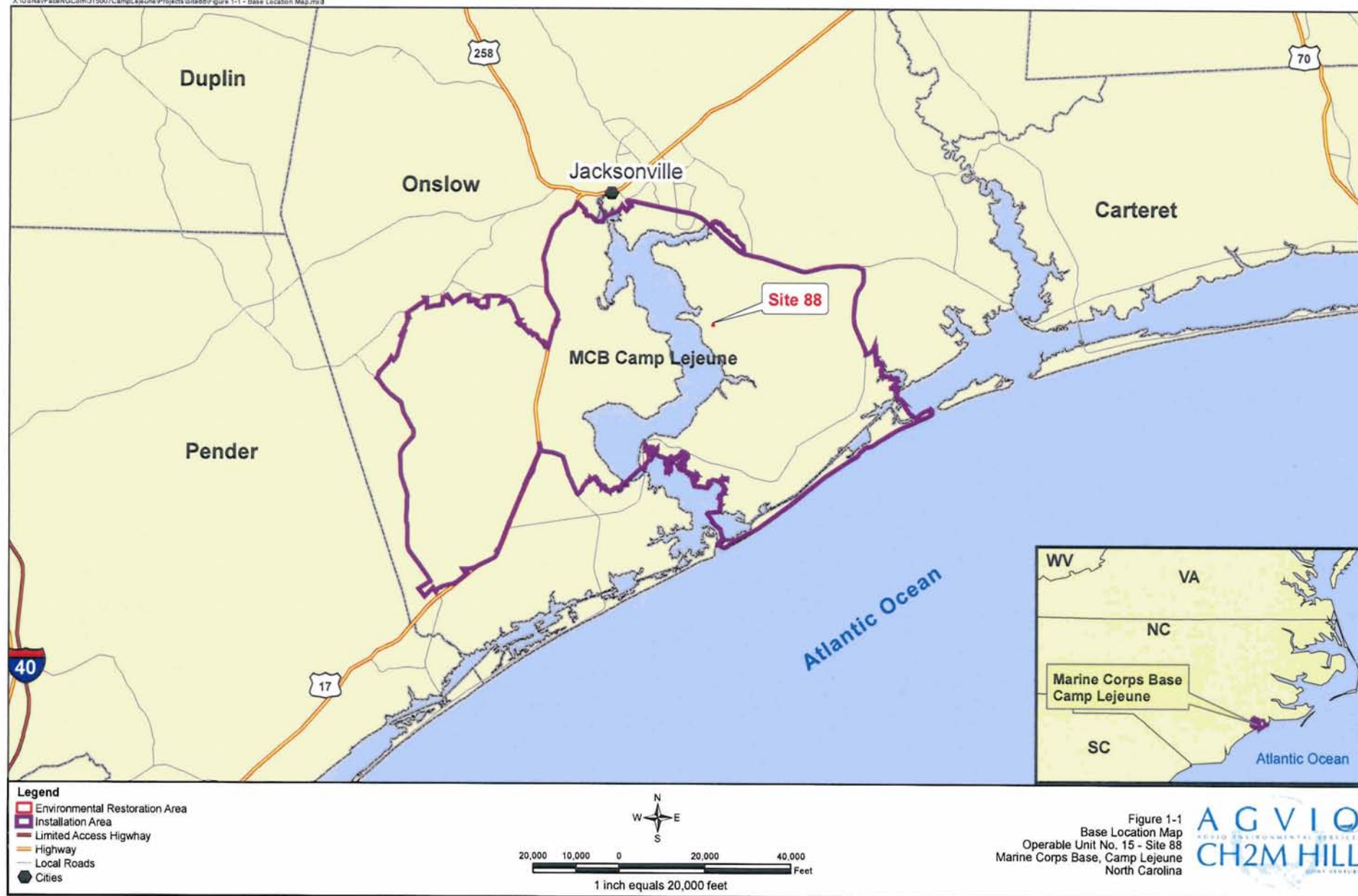
## Notes:

Shaded cells represent exceedances

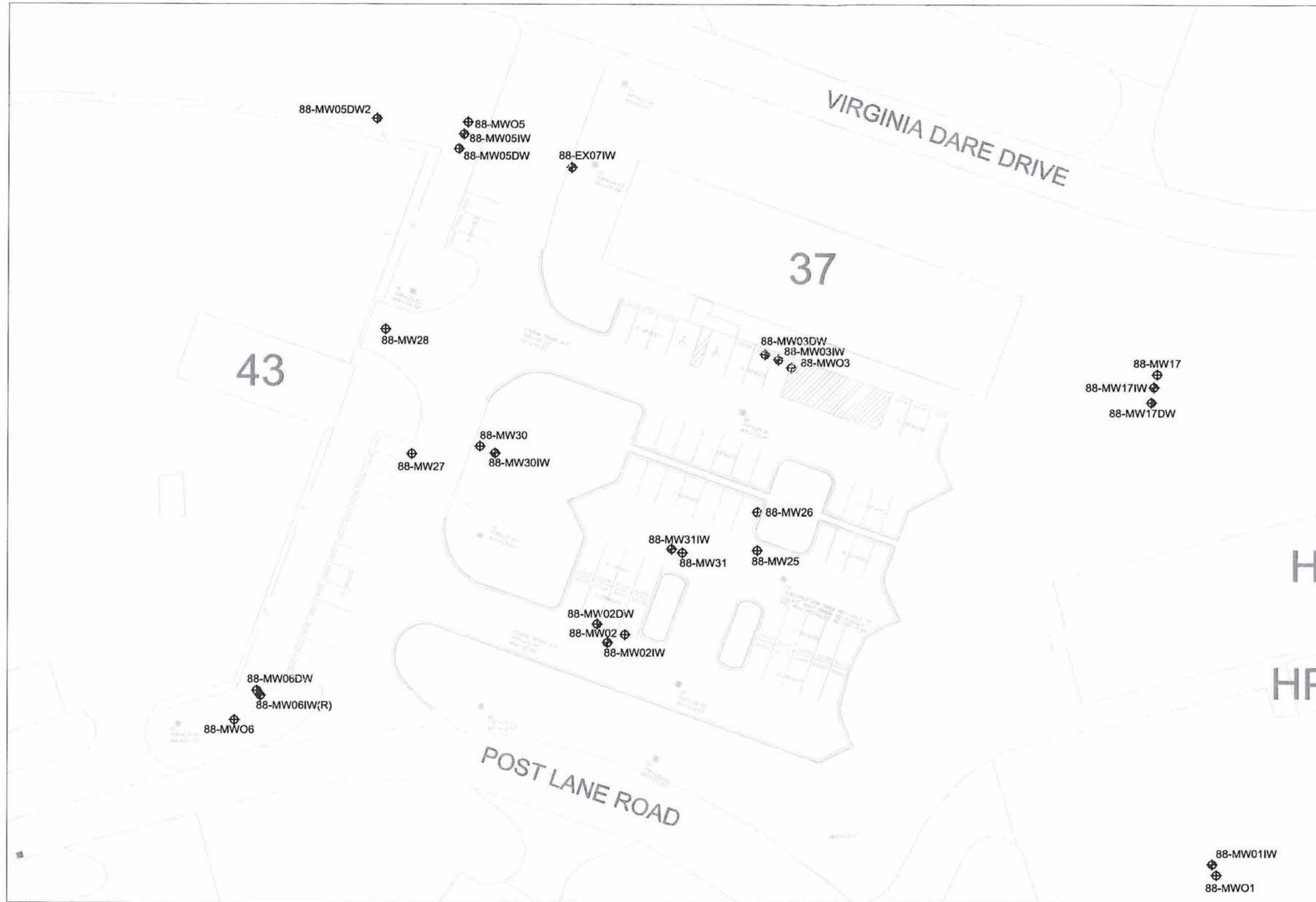
J - Result is estimated

U - Not detected









SOURCE: MCB, CAMP LEJEUNE MARCH 2000

EBL\NAVY CLEAN\CAMPEJCADD\SITE 88\EECA\IMPLEMENTATION PLAN\F\_SITE 88\_FIG.1-2.DWG

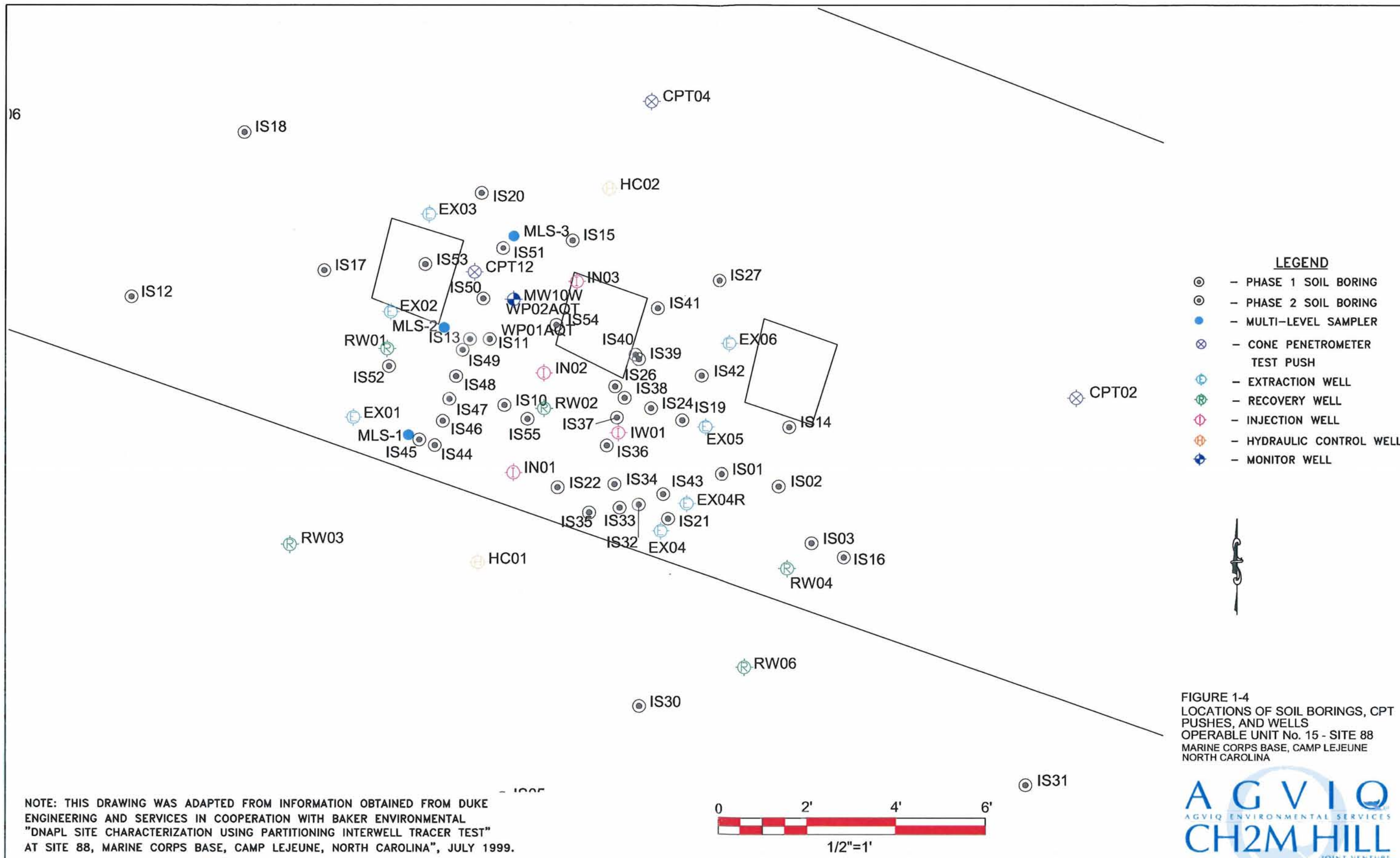
FIGURE 1-2  
SITE PLAN

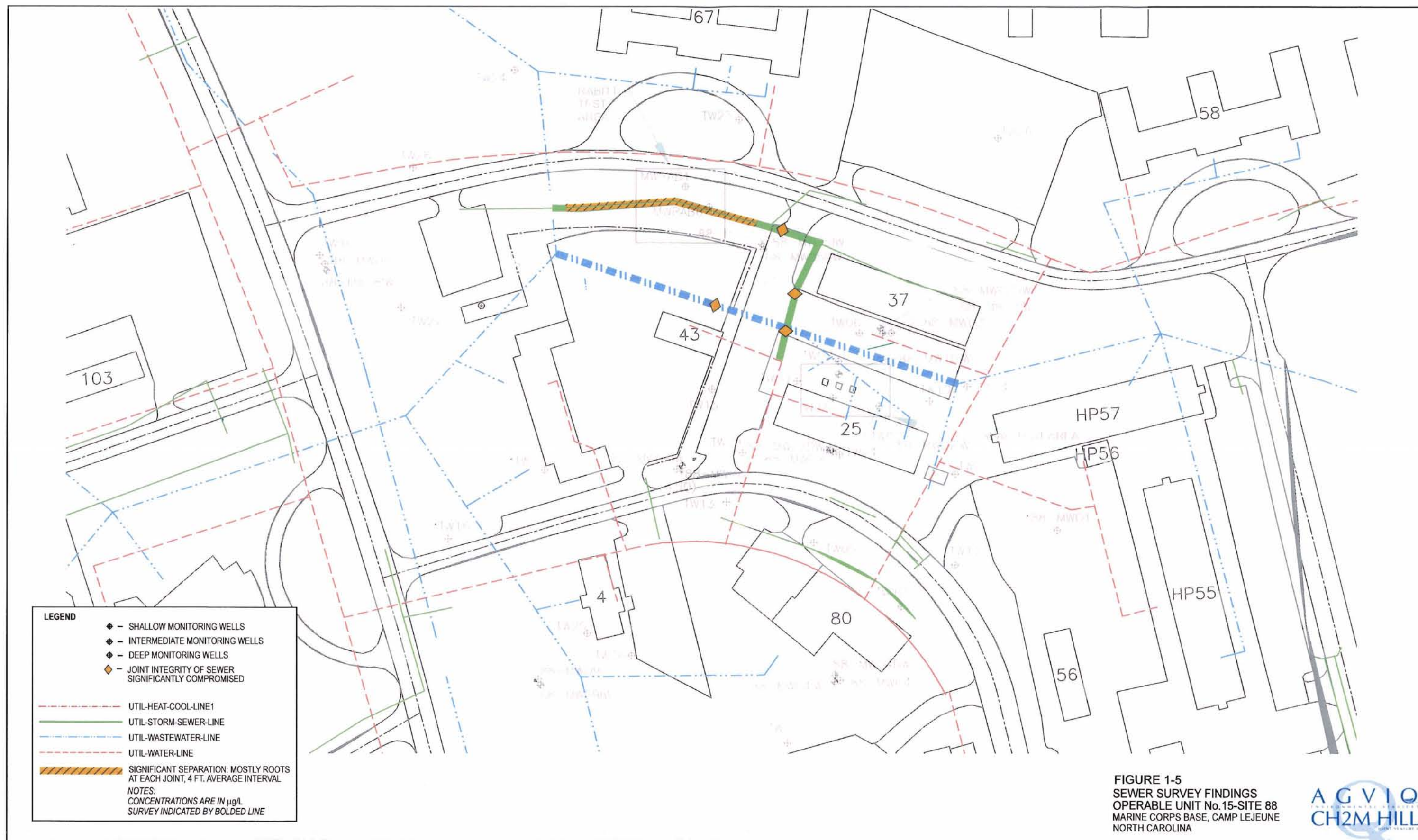
OPERABLE UNIT No. 15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA



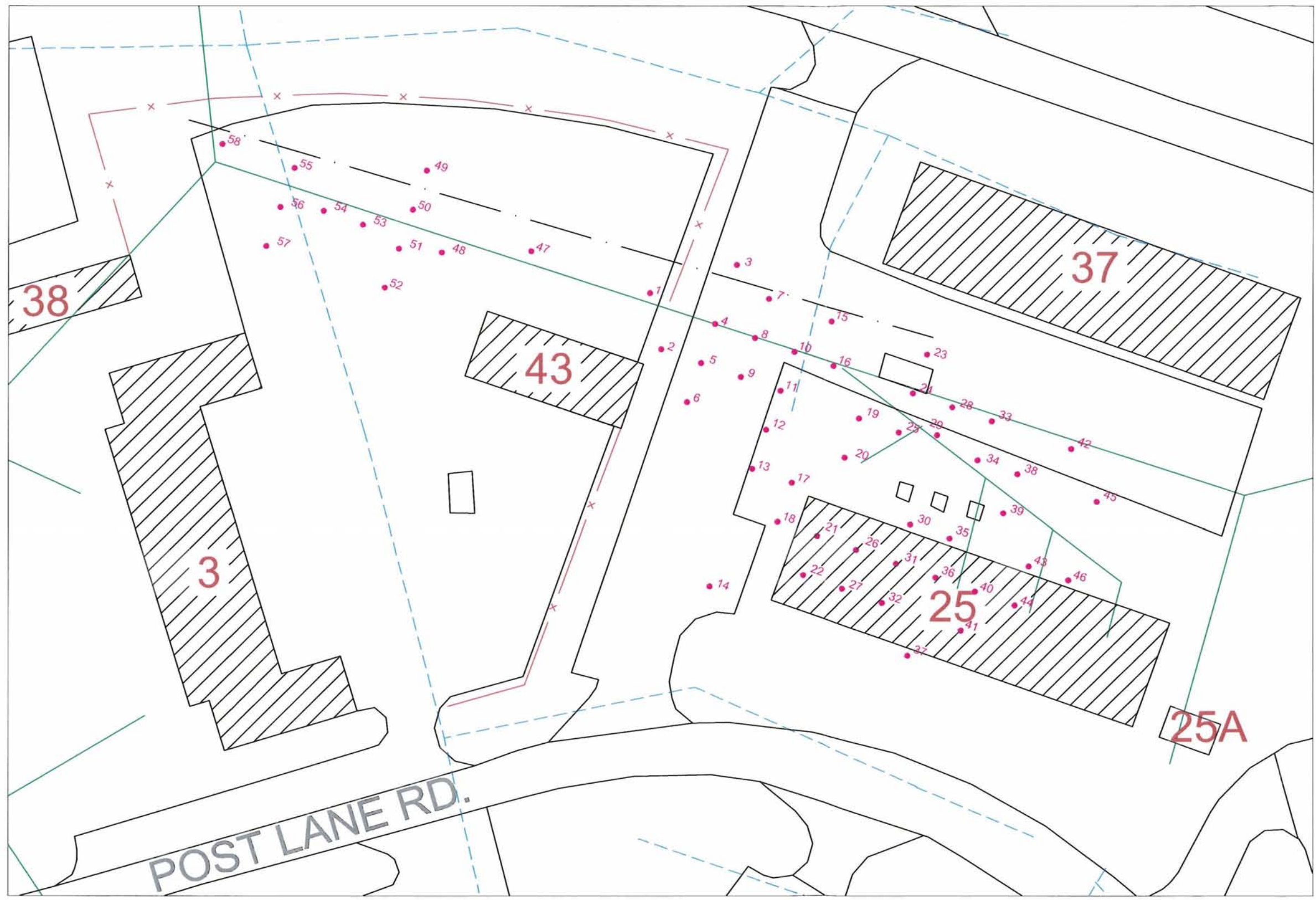












- SANITARY SEWER
- - - STORM SEWER
- MIP INVESTIGATION LOCATION

NOTE:  
APPROXIMATE LOCATION OF SANITARY  
SEWER PRIOR TO 1995



FIGURE 1-6  
MIP INVESTIGATION LOCATIONS  
OPERABLE UNIT No. 15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA



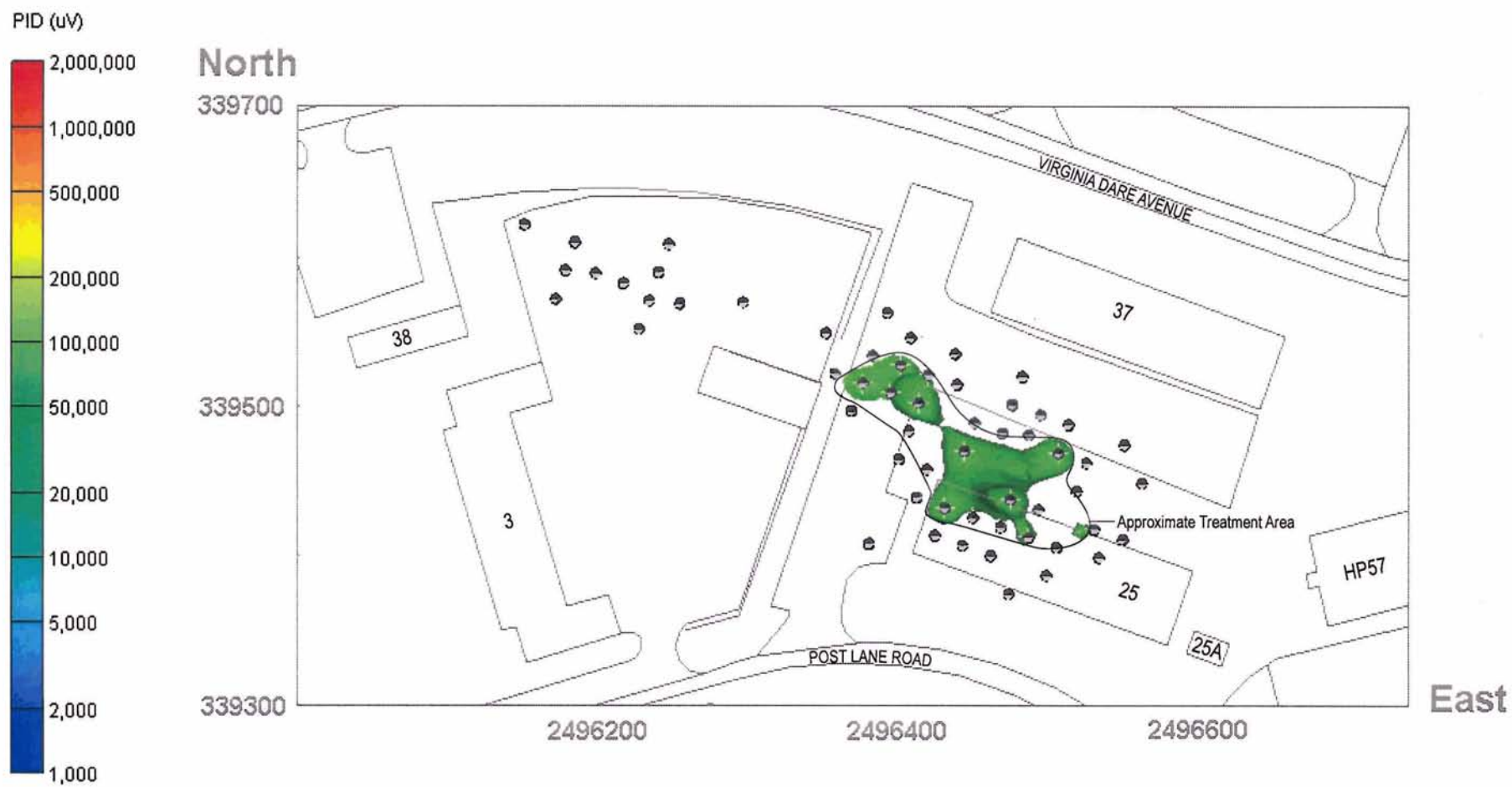


FIGURE 1-7  
HORIZONTAL EXTENT OF THE  
DNAPL SOURCE AREA  
OPERABLE UNIT No. 15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA



North

339700

339500

339300

2496200

2496400

2496600

East

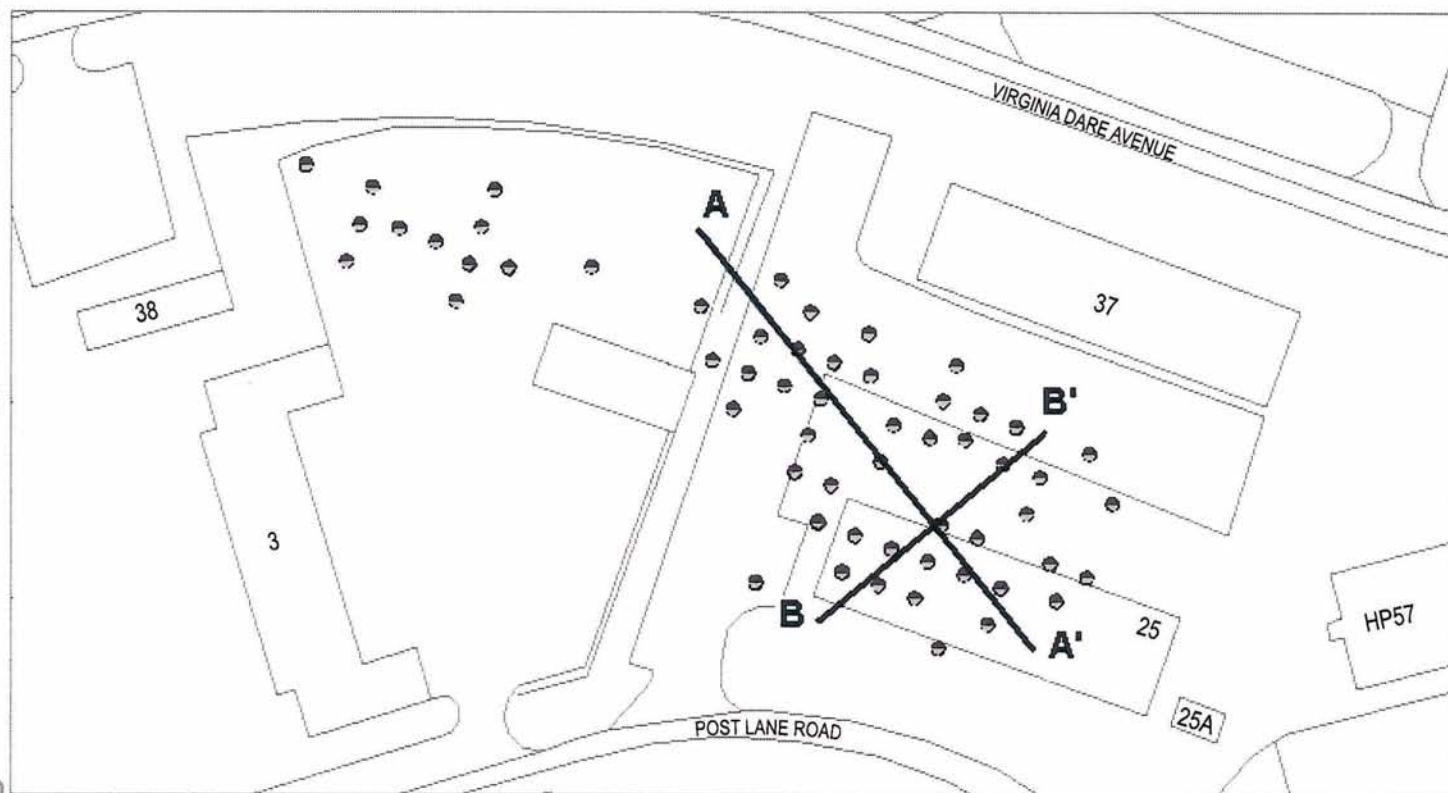


FIGURE 1-8  
VERTICAL DNAPL CROSS  
SECTION LOCATIONS  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

PID (uV)

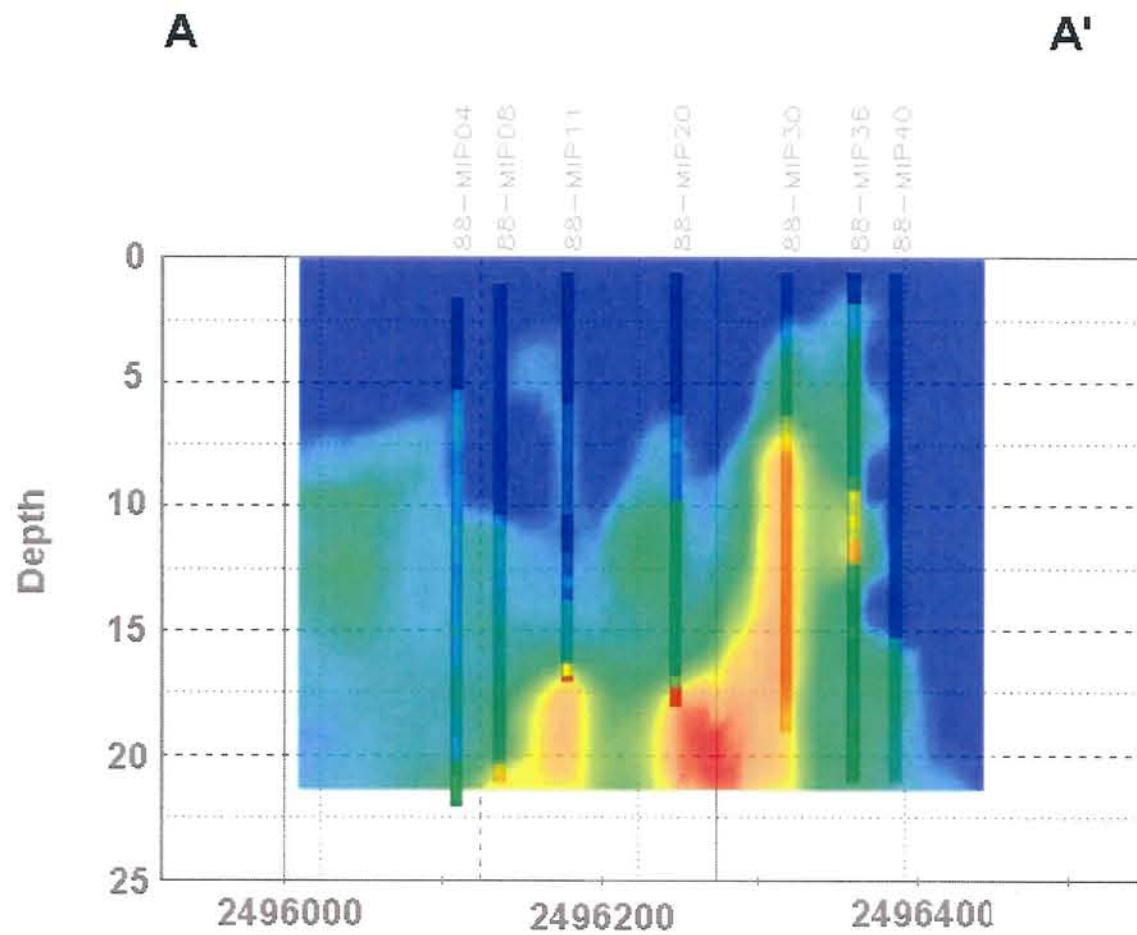
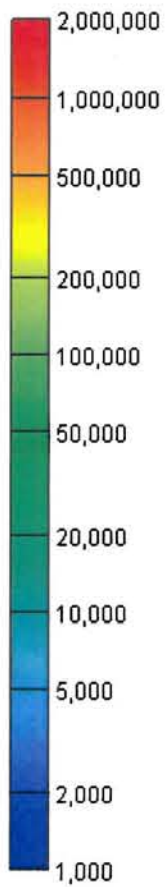


FIGURE 1-9  
PID RESPONSE (uV) ALONG  
CROSS SECTION A-A'  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA



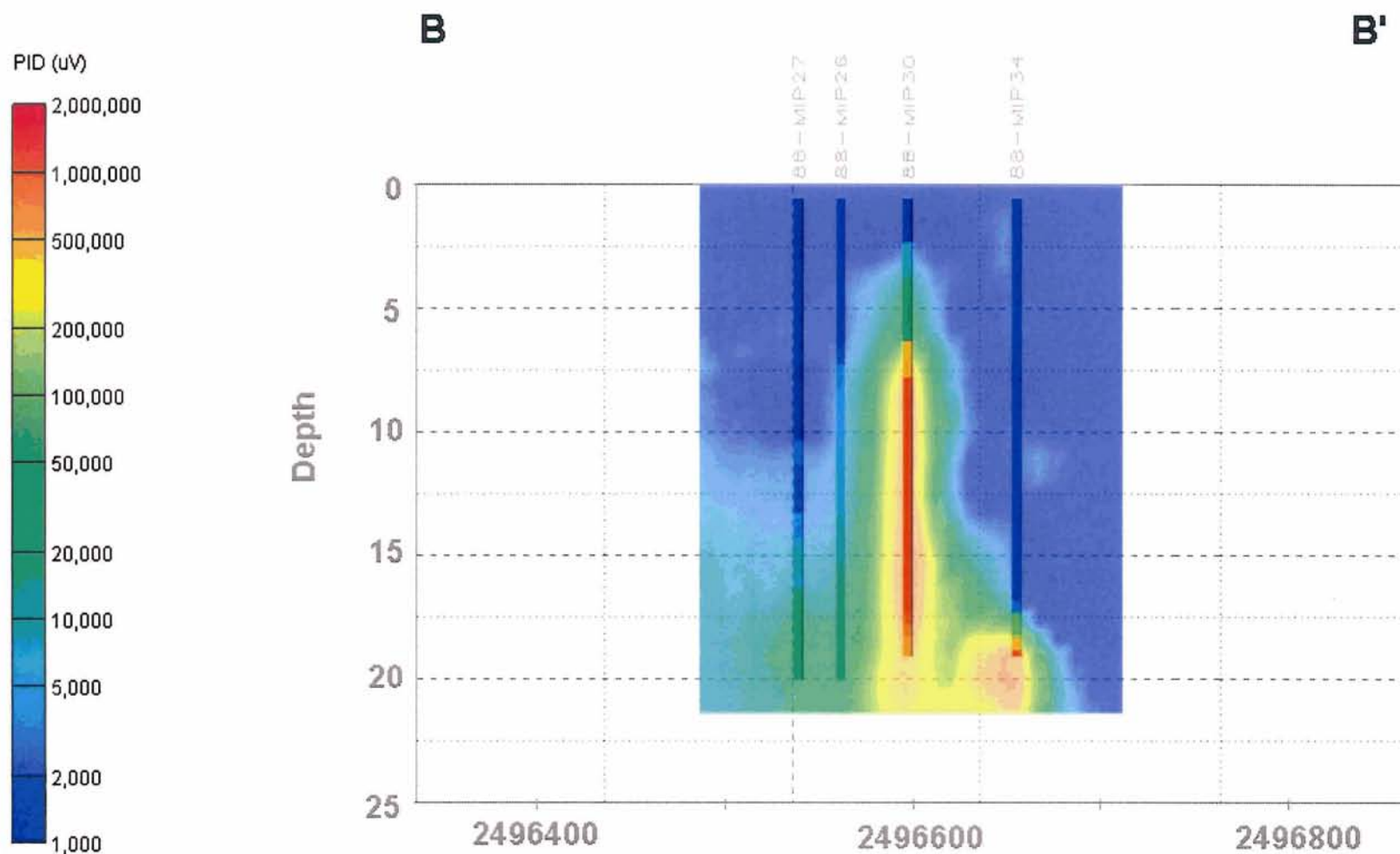
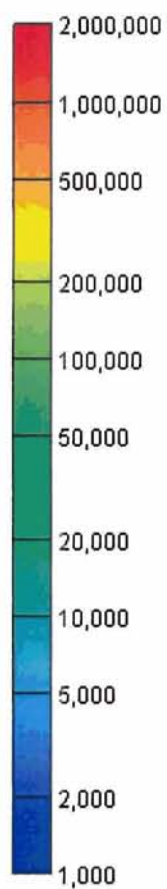
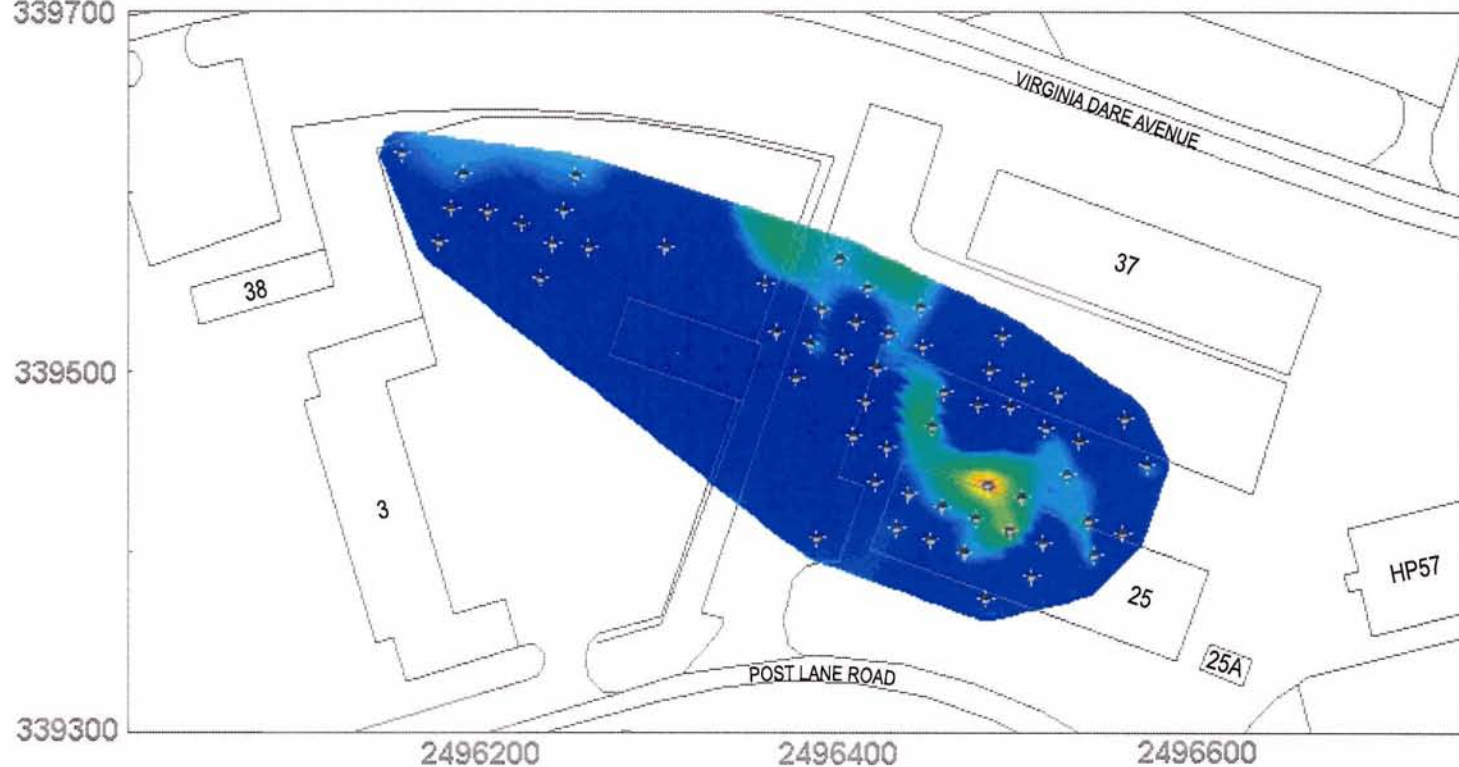


FIGURE 1-10  
PID RESPONSE (uV) ALONG  
CROSS SECTION B-B'  
OPERABLE UNIT No. 15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

PID (uV)



North  
339700



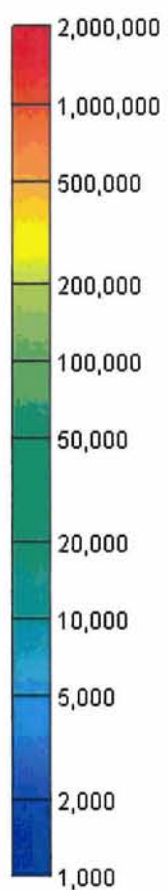
East

FIGURE 1-11  
PID RESPONSE AT 10 FEET BGS  
IN DNAPL SOURCE AREA  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA





PID (uV)



North

339700

339500

339300

2496200

2496400

2496600

East

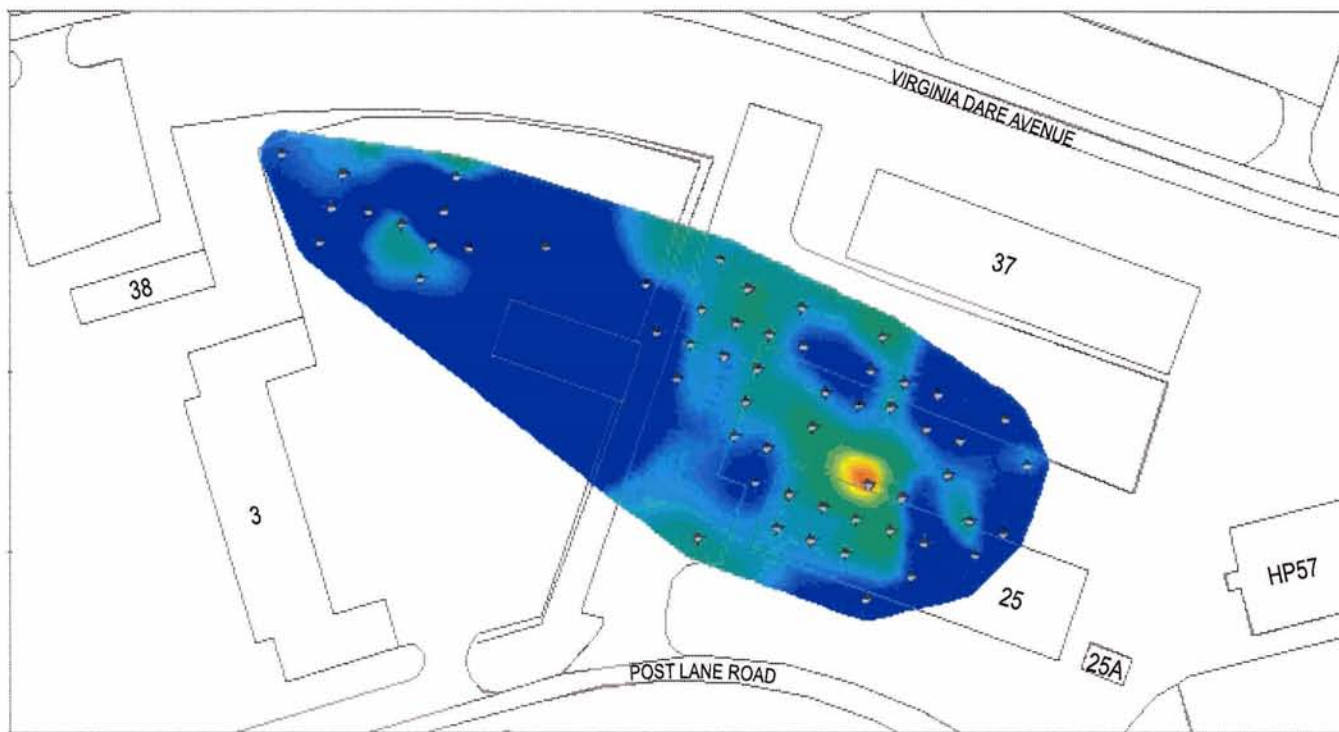
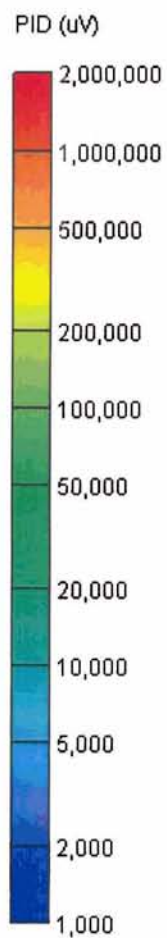


FIGURE 1-12  
PID RESPONSE AT 15 FEET BGS  
IN DNAPL SOURCE AREA  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA





North

339700

339500

339300

2496200

2496400

2496600

East

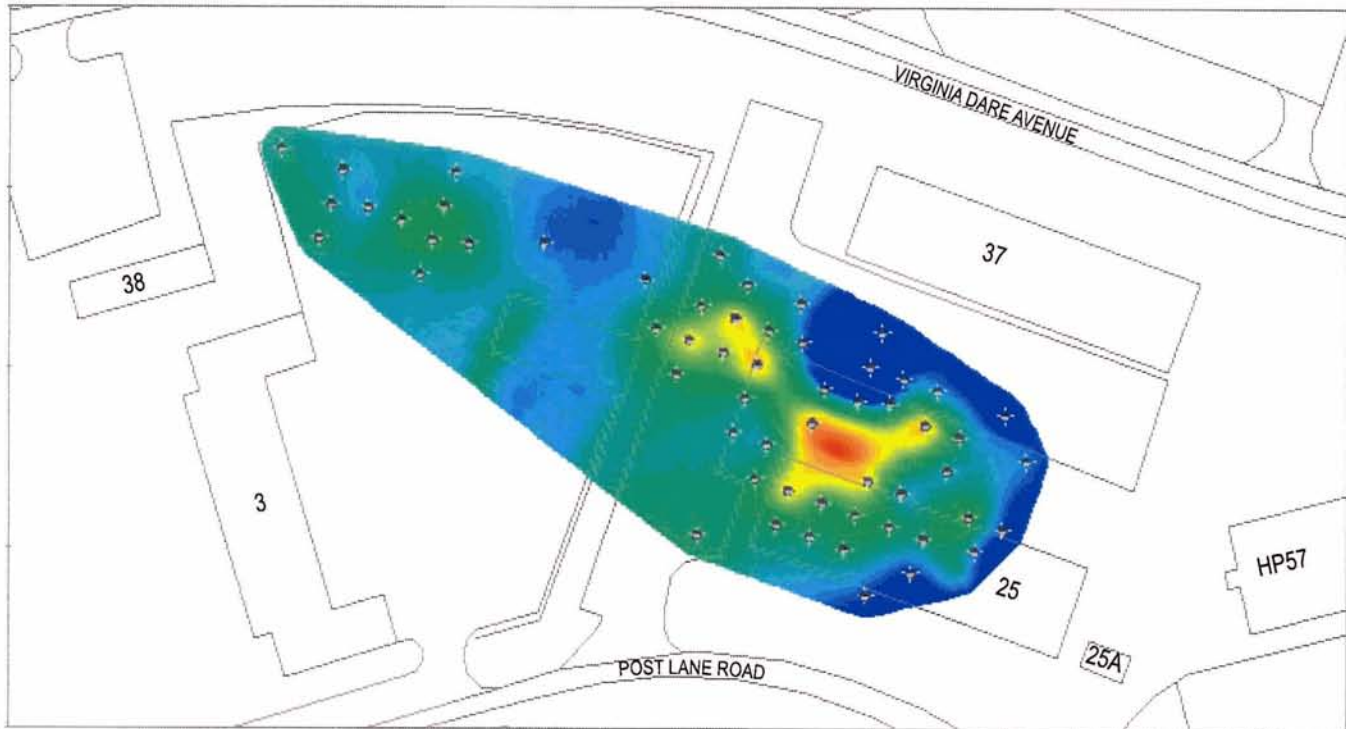


FIGURE 1-13  
PID RESPONSE AT 20 FEET BGS  
IN DNAPL SOURCE AREA  
OPERABLE UNIT No. 15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA





PID (uV)

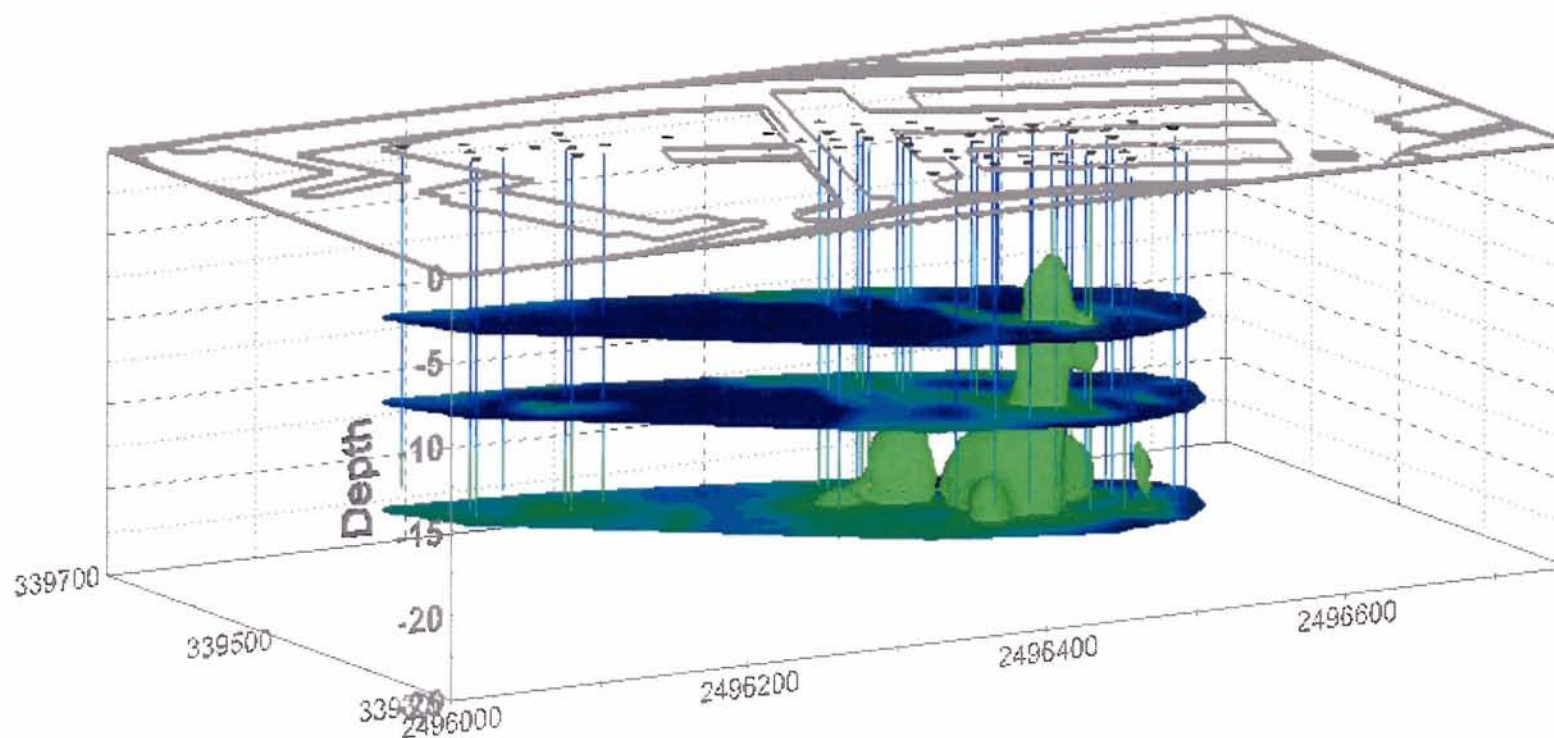
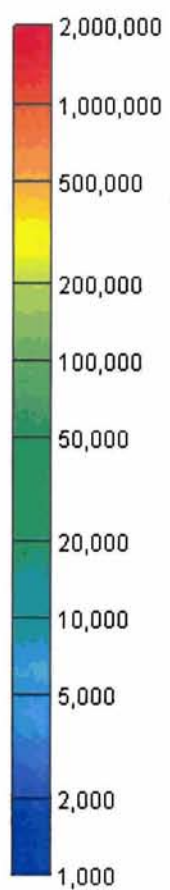


FIGURE 1-14  
VERTICAL DISTRIBUTION OF  
DNAPL IN SOURCE AREA  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA



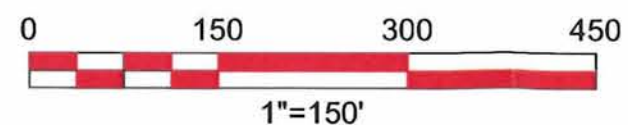
# **LEGEND**

- SANITARY SEWER
- - - STORM SEWER

NOTE:  
APPROXIMATE LOCATION OF SANITARY  
SEWER PRIOR TO 1995



FIGURE 5-1  
UNDERGROUND UTILITY MAP  
OPERABLE UNIT No. 15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

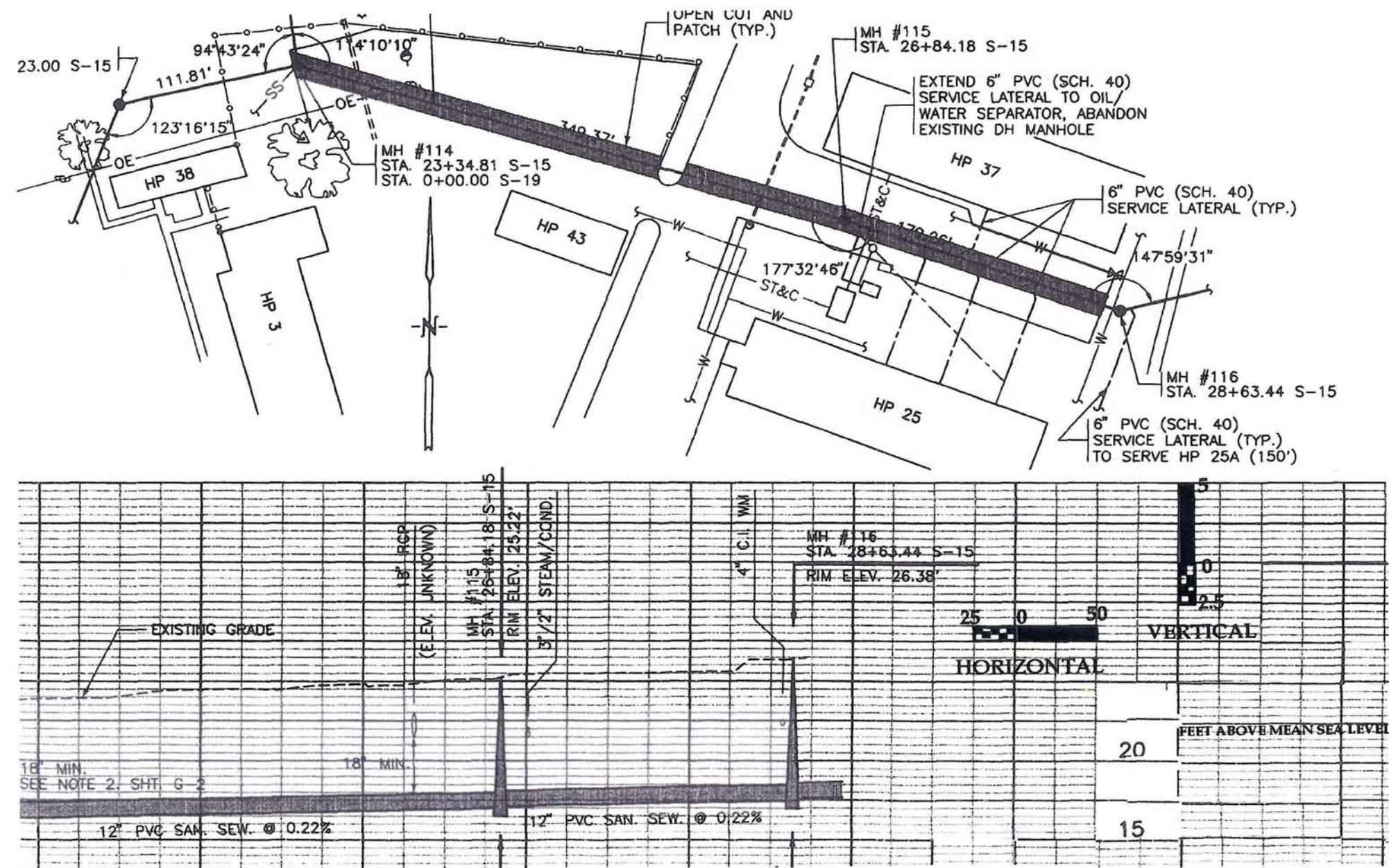


SOURCE: MCB, CAMP LEJEUNE MARCH 2000

EBL\NAVY CLEAN\CAMPLEJCADD\SITE 88\EECA\D\_SITE 88\_FIG.2-1.DWG

**AGVIO**  
AGVIO ENVIRONMENTAL SERVICES  
**CH2M HILL**  
JOINT VENTURE

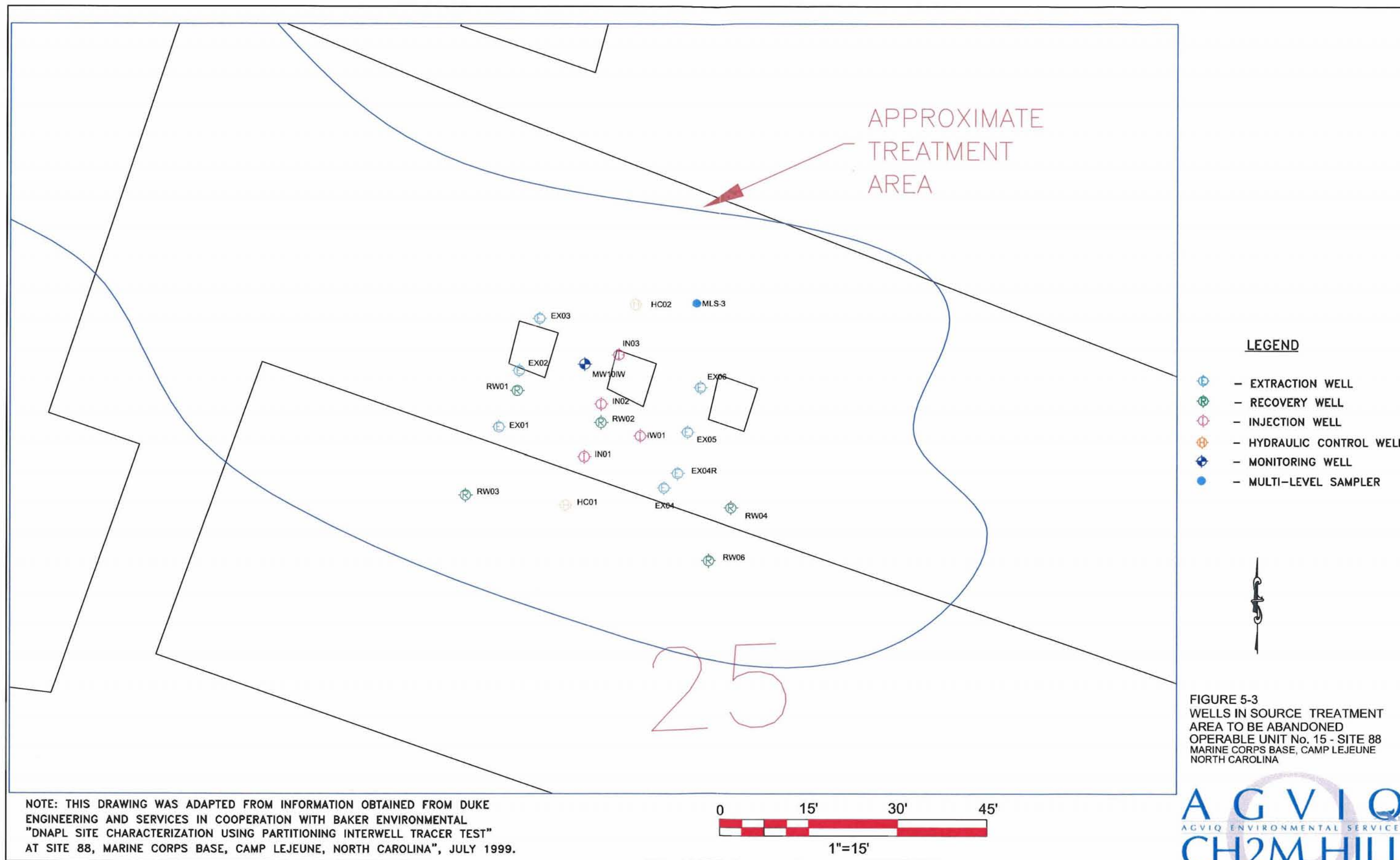




This Figure was obtained by replicating Hobbs, Upchurch, & Associates, P.A. Consulting Engineers of Southern Pines, North Carolina 28387 drawing REPLACE SEWER MAINS, HP AREA Line S-15 STA. 0+00.00 to STA. 28+63.44 NAVFAC Drawing No. 4320771 Code Ident. No 80091 Spec 94-325 Sheet 15 of 25 dated and sealed September 9, 1991 for the Department of the Navy, Naval Facilities Engineering Command of the Marine Corps Base Camp Lejeune, North Carolina.

FIGURE 5-2  
UNDERGROUND UTILITY  
CROSS-SECTION  
OPERABLE UNIT No. 15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA





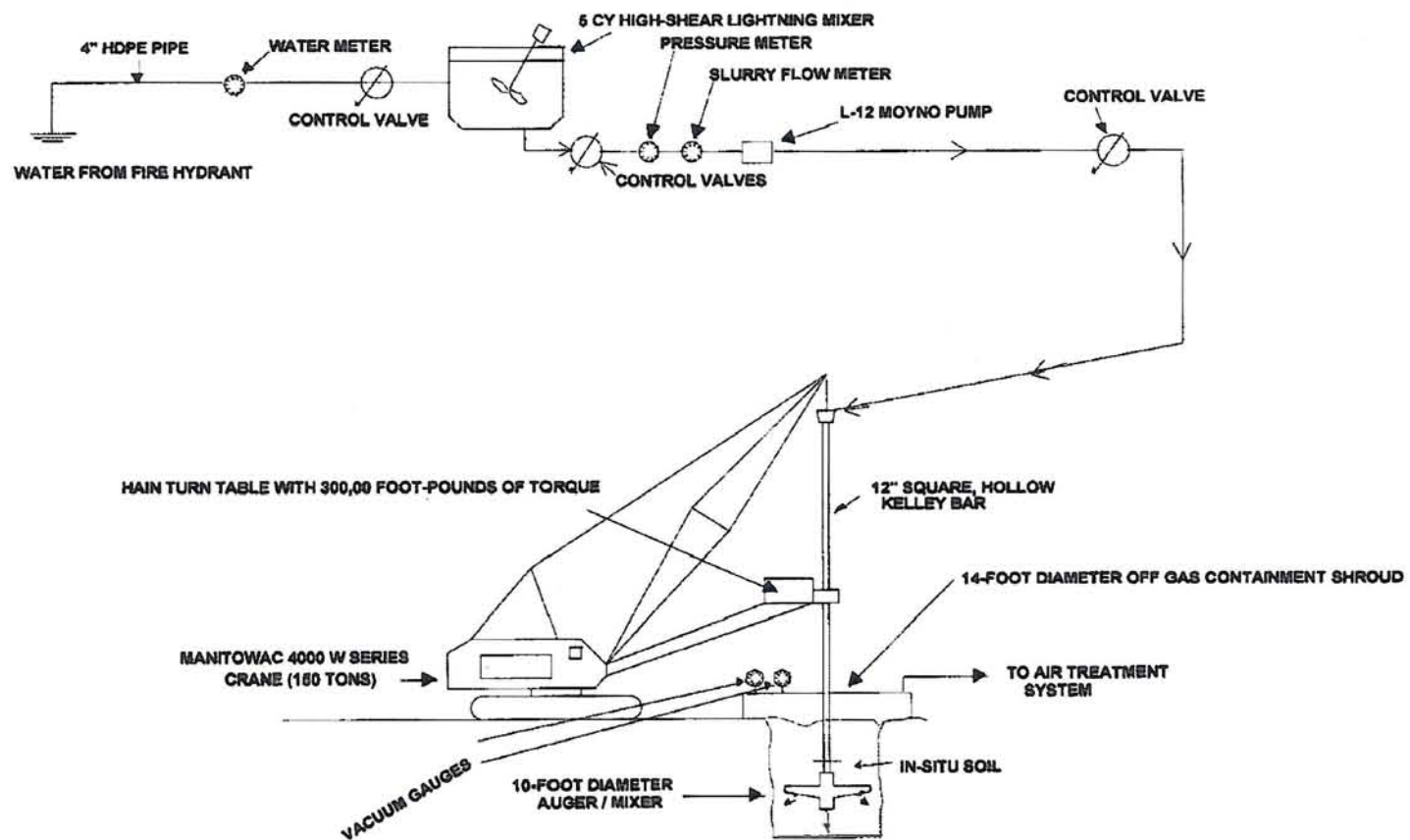
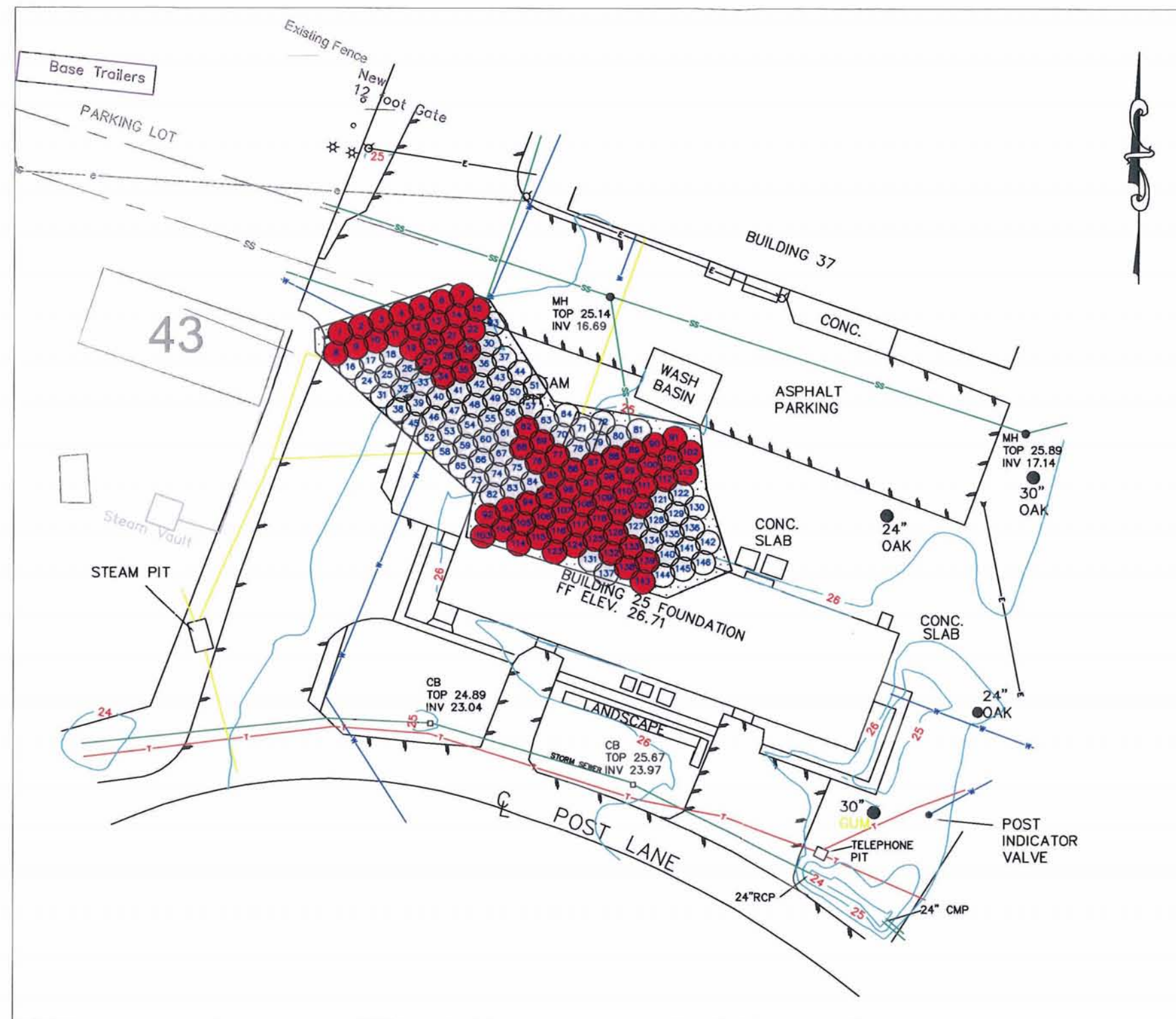


FIGURE 6-1  
MIXING SCHEMATIC  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA





# LEGEND

- SS EXISTING SANITARY SEWER
- W EXISTING WATER MAIN
- E OVERHEAD ELECTRIC
- EXISTING STEAM LINE
- EXISTING STORM SEWER
- T TELEPHONE
- TREE
- POWER POLE
- 2,500 lb ZVI BAGS: 1-15, 19-22, 27-29, 34-35, 62, 68, 69, 76, 77, 85-120, 123-126, 132, 133, 138, 139, 143
- 2,230 lb ZVI BAGS

FIGURE 6-2  
SHALLOW SOIL MIXING  
COLUMN LAYOUT & ZVI DISTRIBUTION  
OPERABLE UNIT No. 15 - SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA



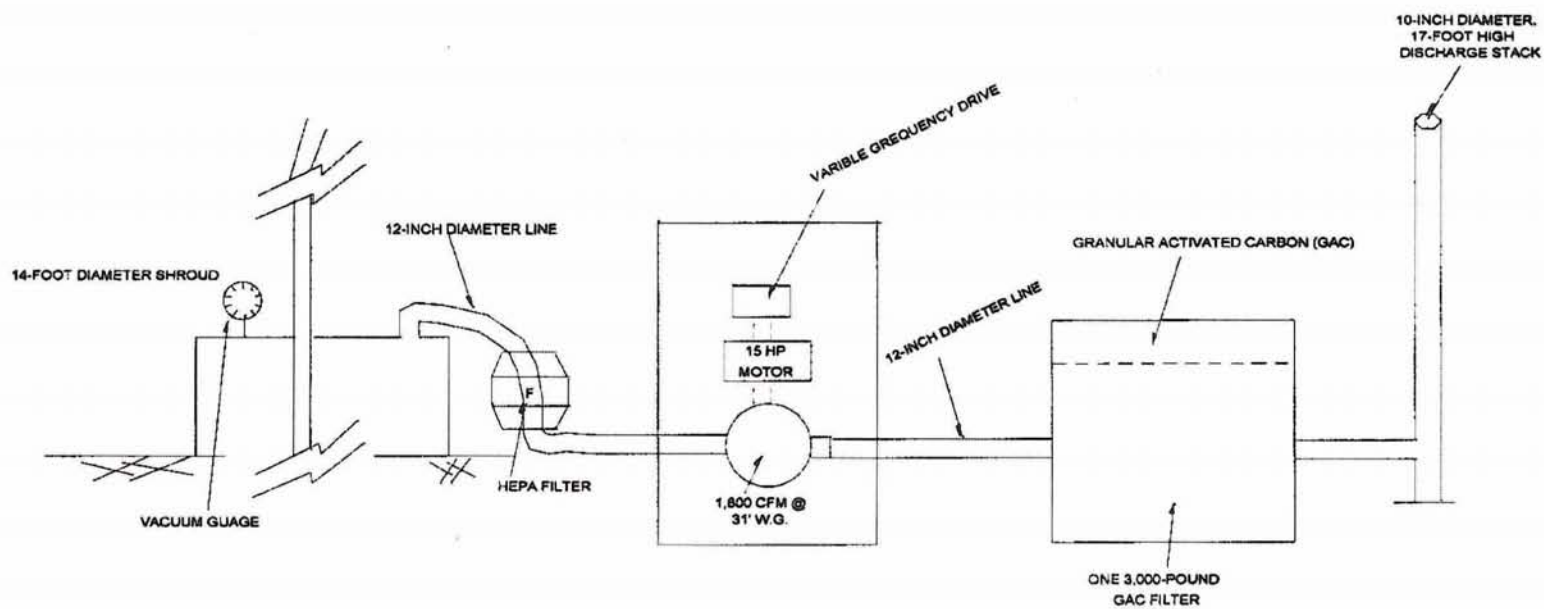


FIGURE 6-3  
 AIR TREATMENT SYSTEM  
 OPERABLE UNIT No. 15-SITE 88  
 MARINE CORPS BASE, CAMP LEJEUNE  
 NORTH CAROLINA



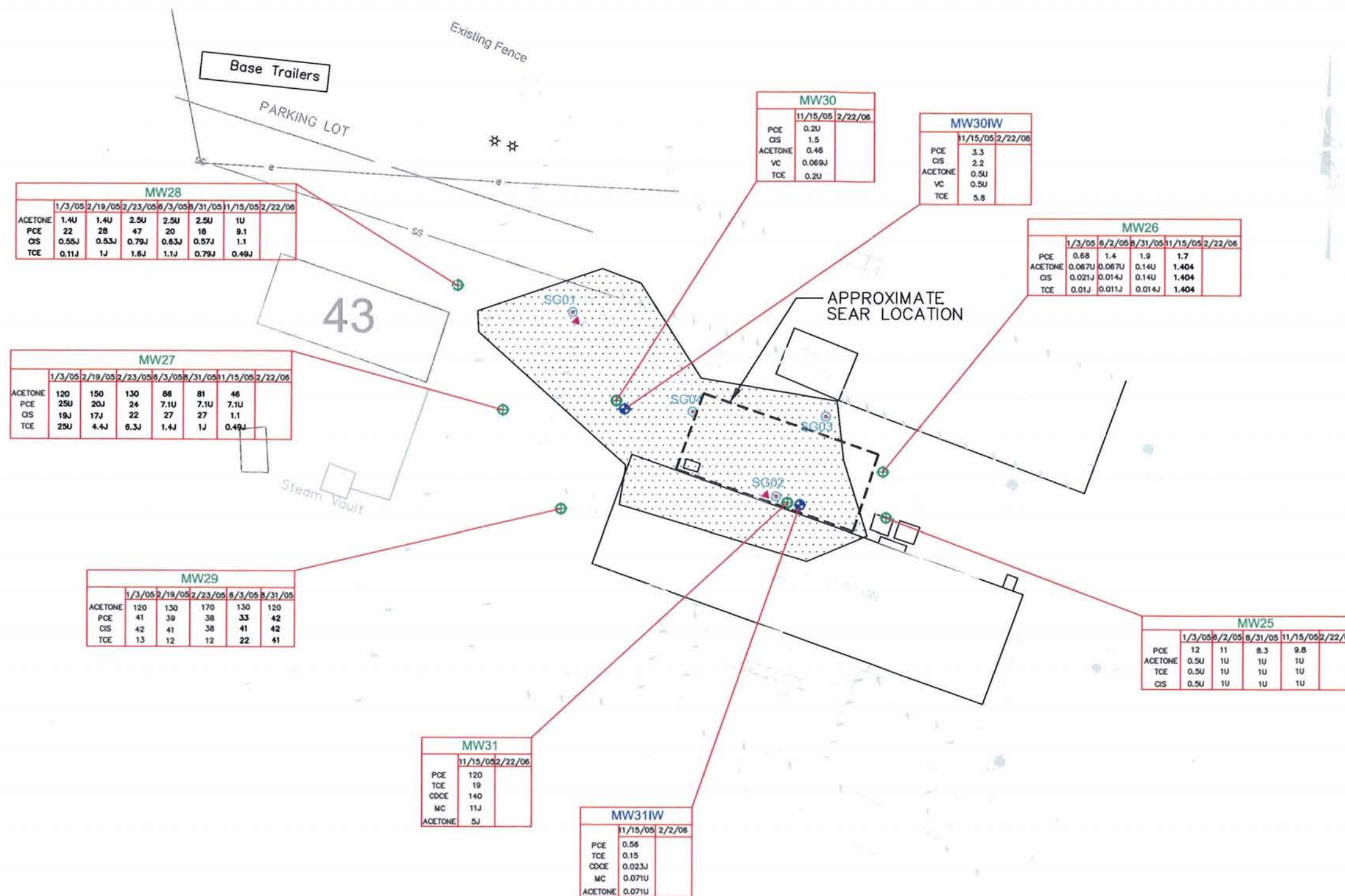


FIGURE 8-1  
GROUNDWATER SAMPLING RESULTS  
JANUARY 2005 TO FEBRUARY 2006  
OPERABLE UNIT No. 15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA





2/15/05		
	5ft	15ft
DCE	NA	NA
TCE	11.6	8.8
PCE	2,722	2,052

		2/15/05		4/26/05		8/3/05		2/17/06		
		5ft	15ft	5ft	10ft	5ft	15ft	10ft	15ft	20ft
DCE	NA	NA	24.0	8.4	0.007	0.270	NA	NA	NA	NA
TCE	12.7	8.8	14.0	16.0	0.019	0.350	<0.20	<0.12	<0.08	<0.08
PCE	1,930	1,514	730.0	340.0	0.18	0.350	0.75	0.52	0.38	0.38

		2/15/05			8/3/05		2/17/06		
		5ft	10ft	15ft	10ft	15ft	10ft	15ft	20ft
DCE	NA	NA	NA	0.250	1.7	NA	NA	NA	NA
TCE	6.6	6.7	8.3	0.005	0.007	<0.15	<0.12	<0.10	<0.10
PCE	982.0	956.0	1460	0.2	0.055	0.40	0.33	0.32	0.32

2/28/05		
	5ft	15ft
DCE	NA	NA
TCE	19.9	34.9
PCE	227.0	90.0

10/19/05				
	5ft	10ft	15ft	20ft
DCE	0.3	3.5	5.7	3.6
TCE	0.3	0.26	0.25	0.28
PCE	0.3	0.26	0.25	0.28

APPROXIMATE  
SEAR LOCATION

		MW31 10/13/05				2/17/06		
		5ft	10ft	15ft	20ft	10ft	15ft	20ft
DCE	0.970	35.0	210	3.0	NA	NA	NA	NA
TCE	1.2	88.0	110	11.0	0.12	10.42	51.31	51.31
PCE	6.8	650.0	4,000	310.0	0.81	479.00	884.52	884.52

2/26/05		
	5ft	15ft
DCE	NA	NA
TCE	8.3	6.2
PCE	1,611.0	774.0

2/23/05	
	5ft
DCE	NA
TCE	10.9
PCE	440.0

		2/24/05		8/4/05		2/17/06		
		5ft	15ft	5ft	15ft	10ft	15ft	20ft
DCE	NA	NA	0.057	37.0	NA	NA	NA	NA
TCE	12.5	13.1	0.280	8.7	1.93	0.76	57.11	57.11
PCE	632.0	651.0	0.280	51.0	10.10	26.69	1,322.91	1,322.91

		2/25/05		4/26/05		8/4/05		10/19/05				2/17/06		
		15ft	5ft	10ft	10ft	20ft	5ft	10ft	15ft	20ft	10ft	15ft	20ft	20ft
DCE	NA	21.0	33.0	19.0	6.6	1.1	0.530	0.043	0.320	NA	NA	NA	NA	NA
TCE	15.9	85.0	0.57	8.5	95.0	0.270	0.220	0.095	0.670	15.50	67.64	52.63	52.63	52.63
PCE	2,247.0	800	0.60	43	3,800	1.0	17.0	15.0	26	14.66	550.18	1,377.20	1,377.20	1,377.20

2/22/05		
	5ft	15ft
DCE	NA	NA
TCE	13.3	12.1
PCE	906.0	670.0

		2/21/05		8/5/05		2/17/06		
		5ft	15ft	10ft	20ft	10ft	15ft	20ft
DCE	NA	NA	9.2	4.4	NA	NA	NA	NA
TCE	8.0	12.3	0.370	2.9	<0.12	<0.12	<0.11	<0.11
PCE	420.0	552.0	0.370	83.0	0.19	0.23	0.22	0.22

## LEGEND

130 SOIL MIXING COLUMN

\* ALL UNITS IN mg/kg

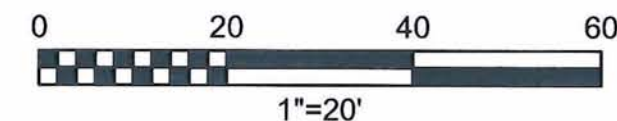


FIGURE 8-2  
SOIL SAMPLING RESULTS  
FEBRUARY 2005 TO FEBRUARY 2006  
OPERABLE UNIT No. 15 - SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

**AGVIO**  
AGVIO ENVIRONMENTAL SERVICES  
**CH2M HILL**  
JOINT VENTURE



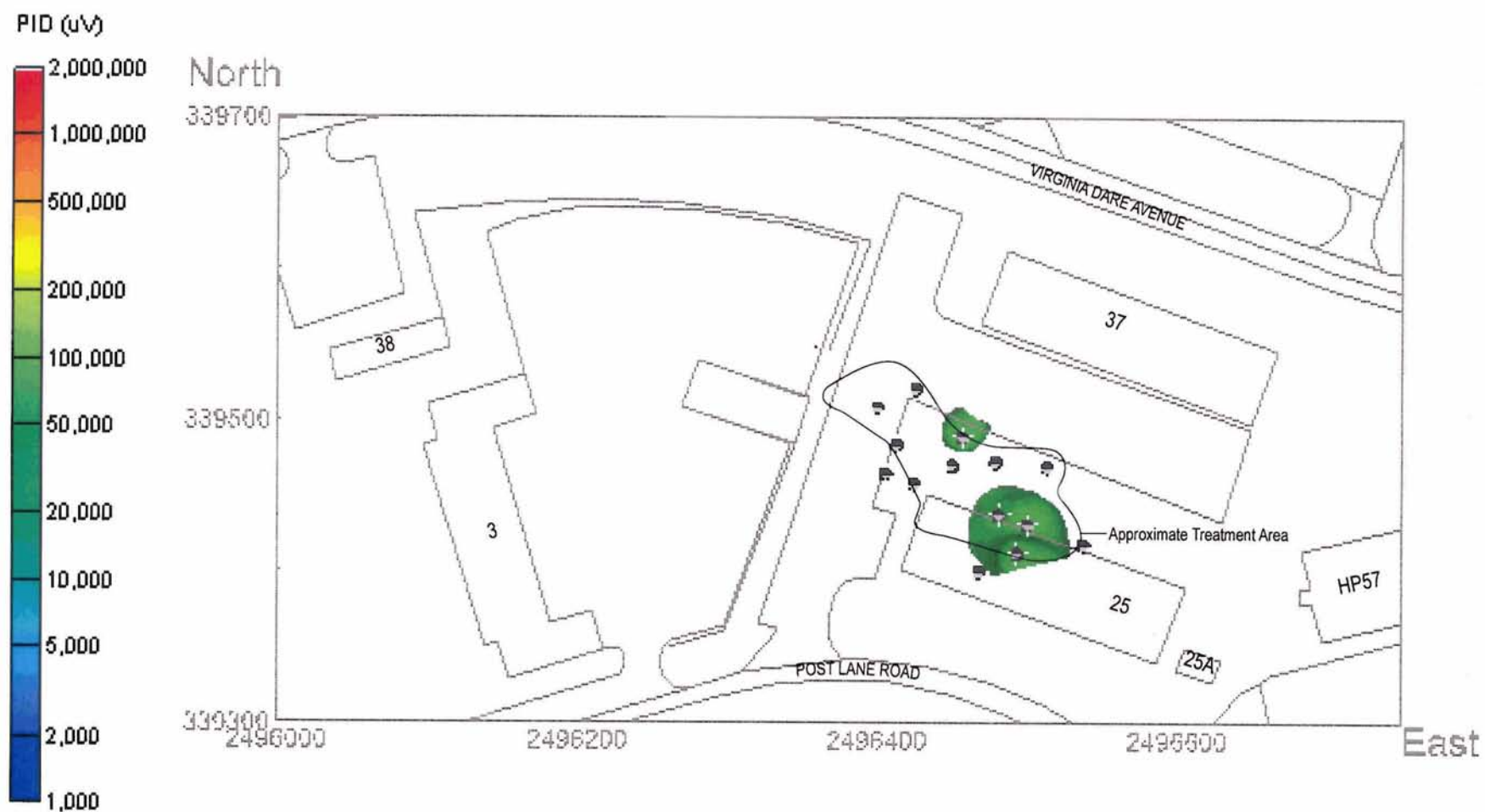
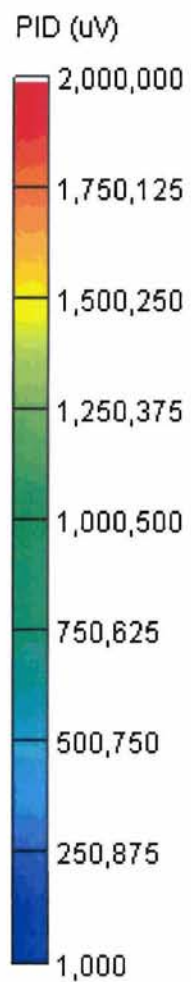


FIGURE 8-4  
HORIZONTAL EXTENT OF THE  
DNAPL SOURCE AREA - POST TREATMENT  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA







North

339700

339500

339300

2496000

2496200

2496400

2496600

East

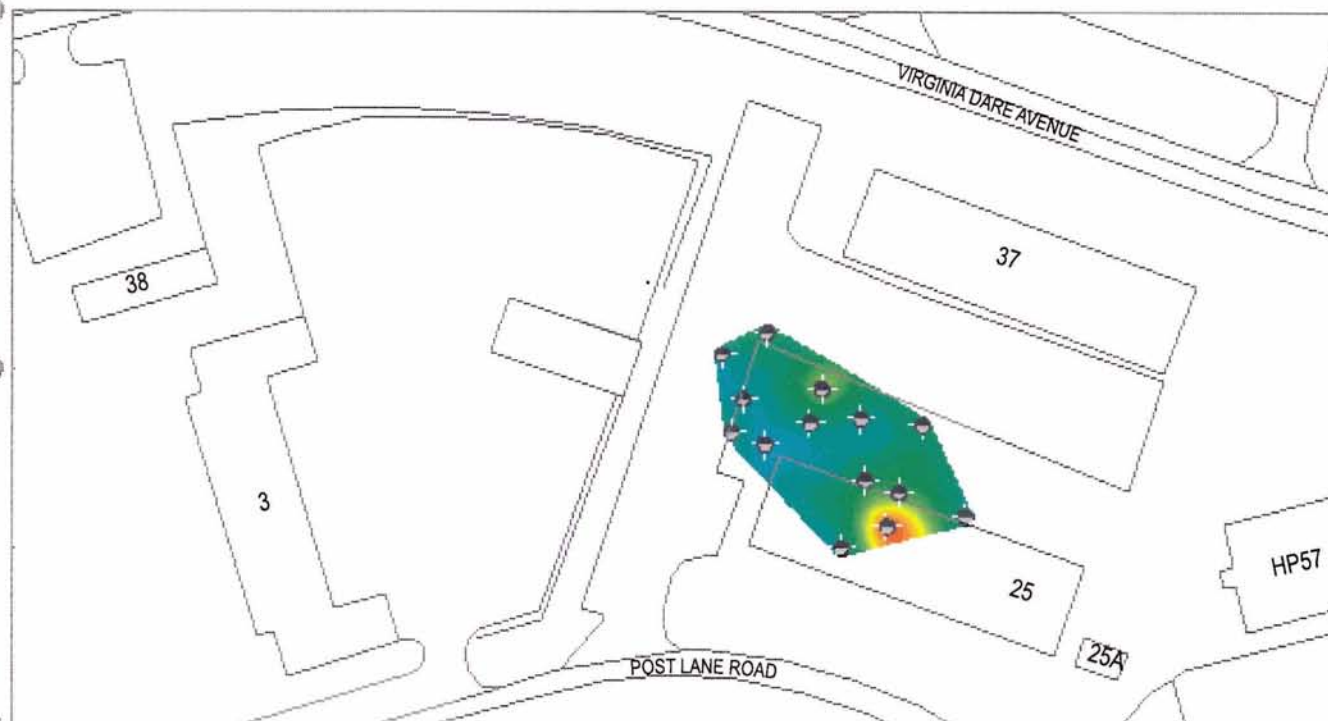


FIGURE 8-6  
PID RESPONSE AT 15 FEET BGS  
IN DNAPL SOURCE AREA - POST TREATMENT  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

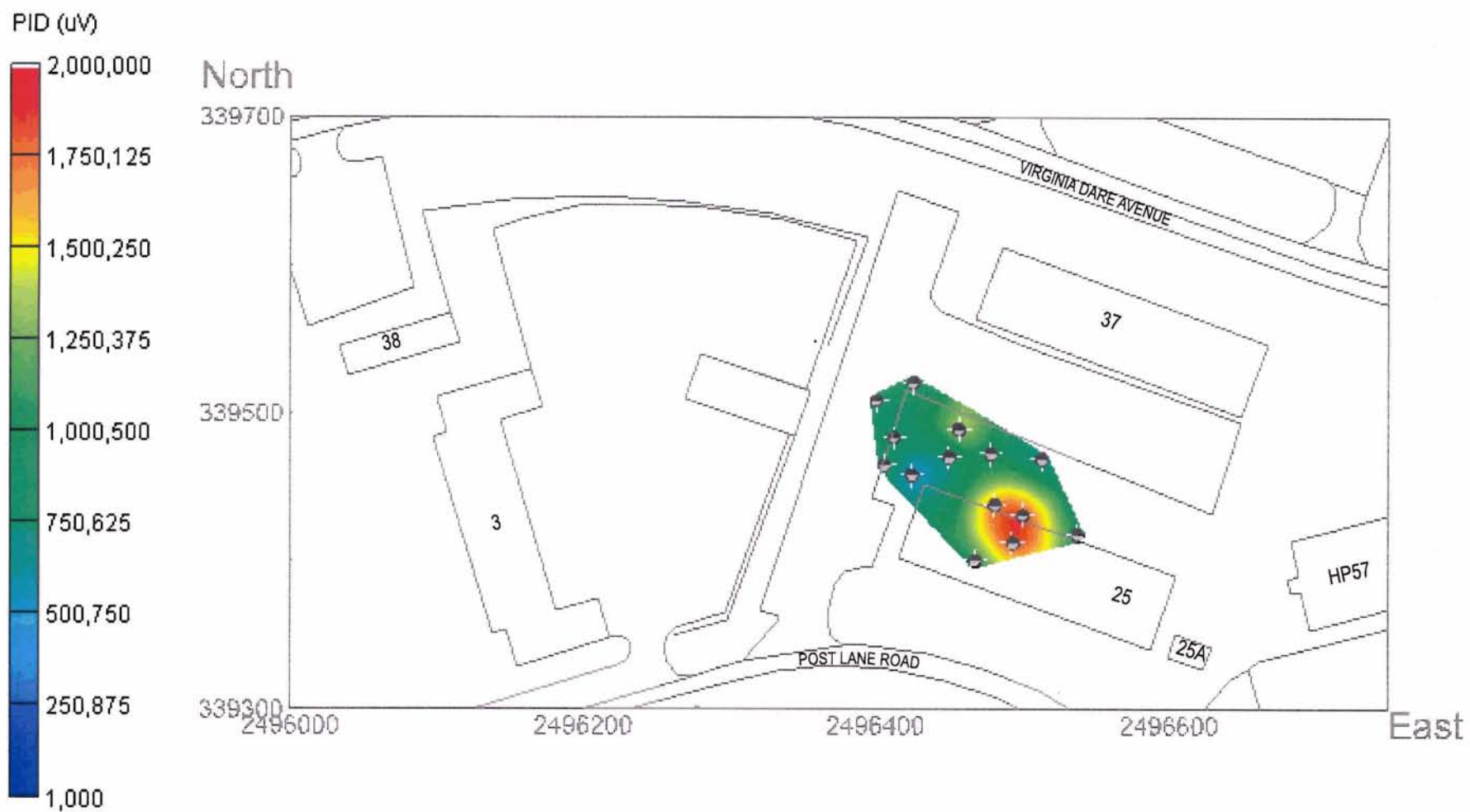


FIGURE 8-7  
PID RESPONSE AT 20 FEET BGS  
IN DNAPL SOURCE AREA - POST TREATMENT  
OPERABLE UNIT No.15-SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

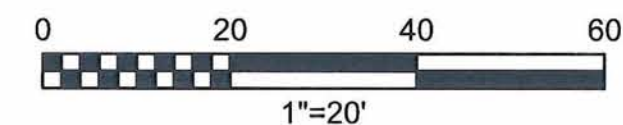


# LEGEND

105 DPT SOIL SAMPLING POINT

130 SOIL MIXING COLUMN

\* ALL UNITS IN mg/kg



APPROXIMATE  
SEAR LOCATION

FIGURE 9-1  
DPT SOIL SAMPLING LOCATIONS &  
SHALLOW SOIL MIXING COLUMN LAYOUT  
OPERABLE UNIT No. 15 - SITE 88  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

**AGVIO**  
AGVIO ENVIRONMENTAL SERVICES  
**CH2M HILL**  
JOINT VENTURE

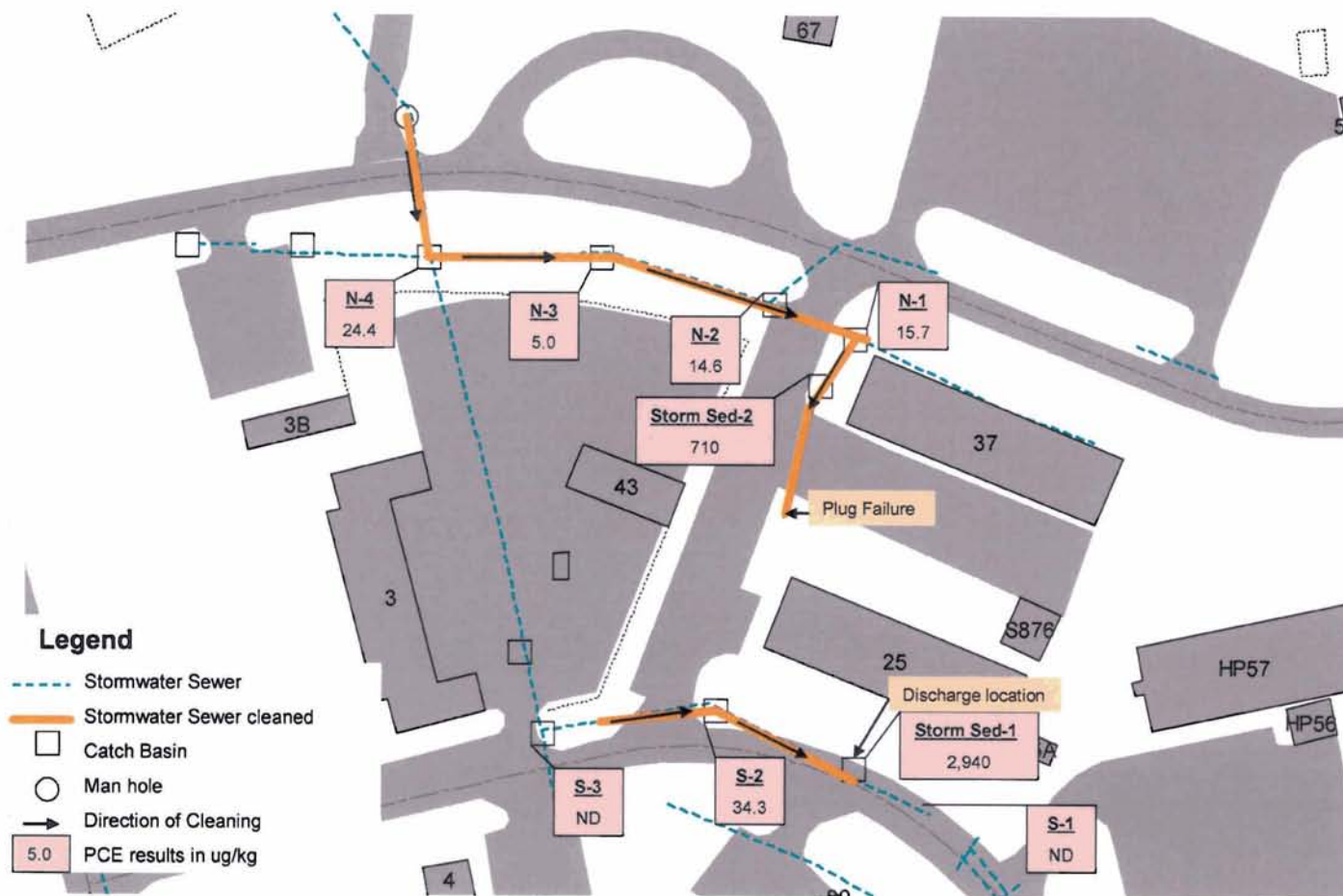


Figure 9-2  
Storm Sewer Sediment Sample  
Locations and Cleaning  
Operable Unit No. 15 - Site 88  
Marine Corps Base,  
Camp Lejeune, North Carolina



# Appendix A

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## Contaminant Mass Estimate

## Appendix A

### Mass of Contaminant Reduction in Pilot Study Area Using CSU Baseline Data

#### Average Dissolved Phase Concentrations (mg/kg):

	Baseline	Final	
PCE	1,097	628.23	*Final average concentration
PCE	1,097	21.50	*Final median concentration

Note: Final concentrations are calculated October sampling events

Density (ton/yd<sup>3</sup>): 1.5  
Treatment area Volume (yd<sup>3</sup>): 7,000

#### Contaminant Mass (lb):

Mass = Conc \* Volume \* Density

	Baseline	Final	
PCE	23,067	13,210	*Final average concentration
PCE	23,067	452	*Final median concentration

Conversion of kg to tons: 907.185

Conversion of mg to lb: 4.53E+05

#### Mass Removal (%):

	% Removal	
PCE	43%	*Final average concentration
PCE	98%	*Final median concentration

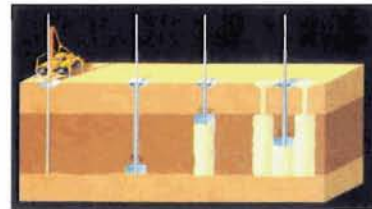


# Appendix B

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Treatability Study Report

# **Camp Lejeune Site 88 ZVI-Clay Pre-Design Studies**



**Developed by**

**Steve Day / GeoSolutions**

**and**

**Tom Sale, Dave Gilbert, David Castelbaum, and  
Mitchell Olson Colorado State University**

**For**

**AGVIQ - CH2M HILL**

**Monday, December 06, 2004**

## EXECUTIVE SUMMARY

AGVIQ, CH2M HILL and the U.S. Navy are currently evaluating the use of in-situ soil mixing with zero-valent iron and clay (ZVI-Clay) to treat a subsurface release of chlorinated solvents at Camp Lejeune, Site 88. As part of this effort, GeoSolutions Inc (GSI) and Colorado State University (CSU) have conducted laboratory studies that characterize the potential to treat perchloroethene (PCE) and associated degradation intermediates using ZVI-Clay. Results indicate that the target compounds can be degraded and provide a basis for resolving some aspects of field implementation.

As a first step, CH2M HILL collected 153 soil cores and three 40 mL vials of DNAPL from Site 88. The soil cores were shipped to CSU for inclusion in laboratory studies. Soils were logged and split into six composite samples, including samples for 1) composite soil properties, 2) analysis of the efficacy of ZVI-Clay treatment, 3) mixed DNAPL distribution studies, 4) hot air flushing studies, 5) post mix studies, and 6) archiving. Contaminants observed in the composite samples (post sample handling) include PCE (~ 5 mg/kg) and trace levels of TCE and DCE. The soils consist of varying combinations of fine sand, silt, and clay.

The studies to evaluate ZVI-Clay efficacy for treatment of PCE (and associated compounds) involved two components: unspiked soil and DNAPL spiked soils. The experimental setup for the unspiked soils involved 1) admixing varying amounts and types of iron with bentonite clay and soils collected from Site 88 and 2) measuring concentrations of target compounds at 3, 7, 14, 31 and 59 days. The spiked soil study involved addition of DNAPL (collected from Site 88), admixing varying amounts and types of iron with bentonite clay and the spiked soils, and measuring concentrations of target compounds at 3, 7, 14, 31 and 59 days.

Primary results include:

1. Approximately 75% decrease in PCE is seen over the 59-day study. Extrapolating the observed degradation rates through time, it appears that the vast majority of PCE can be depleted in a period of a year or less.
2. Significant accumulation of TCE, DCE isomers, or VC is not observed.
3. Studies with 1, 3, 5 and 7 % Peerless<sup>TM</sup> iron (dry soil weight basis) indicate faster rates of degradation with greater amounts of iron. However, similar overall decreases were observed after 59 days. Assuming reaction rates remain constant, and considering periods of a



year or more, a similar endpoint could be achieved with any of the iron treatments. The only difference might be how quickly the endpoint is reached.

4. DNAPL spiked studies indicated slightly lower rates of removal and lower reaction rate constants compared to the unspiked study. Half-life estimates are approximately 30 days for the DNAPL spiked soil compared to approximately 20 days in the unspiked soils.
5. Data from 1 % GMA<sup>TM</sup> and 1 % Peerless<sup>TM</sup> iron spike studies show similar rates of contaminant removal.

In addition, two column mix studies were conducted. In the first, PCE DNAPL pools were emplaced at the midpoint of three soil columns. Simultaneous mixing and injection of ZVI-Clay dispersed the DNAPL without affecting apparent adverse downward DNAPL migration. In the second set of column studies, addition of ZVI-Clay with and without hot air injection was compared. No significant improvement in performance was observed with hot air injection. Analysis of soils from both sets of column studies verifies the apparent rate of PCE treatment seen in the ZVI-Clay efficacy studies. Observed expansion of soil through treatment in these studies was 12-15%. Theoretical calculation using conservative assumptions indicates expansion could be 25%.

Delivery of ZVI and Clay is accomplished by injecting a water-based grout containing ZVI and Clay. The grout suspends the reagent (granular iron) for transfer through the equipment and into the soil, and satisfies the functions of a drilling fluid. The basic proportions and properties of identified grout are:

- Bentonite per weight of water = 7%
- ZVI per weight of water = 14%
- Grout density = 72 lbs/ft<sup>3</sup>

It is expected that the Marsh funnel viscosity of the grout will be about 50 to 60 seconds. This may require modification in the field.

Lastly, studies were conducted to evaluate the effect of adding cement to the upper portion of the treated interval. It appears that ~ 6% Portland cement added to the ZVI-Clay treated soils would stabilize the surface to provide access over the treated areas and sufficient soil strength for parking lot land use.

## **DISCLAIMER**

GeoSolutions Inc. and Colorado State University provides no guarantees or warranties regarding the performance of the ZVI-Clay technology at a field-scale or over extended periods. Parties utilizing information presented herein need to recognize that: 1) conditions in the field can vary from those in the laboratory; 2) the performance observed during the relatively short duration of the laboratory studies does not guarantee long-term performance; 3) all aspects of the ZVI-Clay treatment process are likely not understood at this time; and 4) success at a field scale will be highly dependent on field delivery and mixing of reactive media, stabilizing agents, and target compounds.

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## 1 INTRODUCTION

In August 2004, AGVIQ - CH2M HILL contracted GeoSolutions Inc. (GSI) and Colorado State University (CSU) to conduct laboratory studies in support of using ZVI-Clay Source Zone Technology at Site 88, Camp Lejeune, North Carolina. In early September of 2004, site soils were sent to Colorado State University (CSU) and a series of laboratory studies were completed over an approximate 10 week period. Objectives of the studies include:

- 1) Generating laboratory data that supports analysis of the efficacy of treating the source contamination using zero valent iron and clay (ZVI-Clay) in conjunction soil mixing.
- 2) Evaluating the effect of ZVI-Clay and soil mixing on Dense Nonaqueous Phase Liquid (DNAPL).
- 3) Generating qualitative data regarding the potential of hot air flushing as a complementary treatment.
- 4) Generating laboratory data that supports design of slurry and/or grout mixtures to be used including clay and iron content.
- 5) Providing a basis for estimating volume expansion due to ZVI-Clay treatment.
- 6) Characterizing soil strength associated with cement stabilization.

As a brief introduction, Figure 1 presents a site photo. Primary contaminants of concern are perchloroethene (PCE) and associated products of reductive dechlorination. The PCE is associated with a former dry cleaning facility located at the site. Subsurface contamination occurs as DNAPL, dissolved constituents in groundwater, and a sorbed phase on the soil. The presence of DNAPL is based on observations of PCE DNAPL in a well. Sediments in the area of concern consist of unconsolidated alluvium composed primarily of sand and silts. A comprehensive introduction to the site is presented in CH2M HILL (2004).



Figure 1 - Site 88, Camp Lejeune



## 2 METHODS

### 2.1 Bulk Soil Samples

On August 26<sup>th</sup> 2004 CH2M HILL shipped eight coolers containing 153 soil core segments ( ~2 inch by 12 inch) and three 40 mL vials containing DNAPL to CSU. The coolers were received at CSU on August 27<sup>th</sup>. Contents were received in good condition. Upon receipt, the core segments and DNAPL were transferred to refrigerators in access controlled CSU laboratories.

On September 2<sup>nd</sup>, 2004 148 soil core were opened inside a laboratory fume hood and split into six composite samples as shown in Figure 2 and outlined in Table 1. Properties of the cores including weight, length, density, detected organic vapors, and visual descriptions are presented in Appendix A. The observed soils ranged from well-sorted fine sand to fine sand with silt to silt with clay. Color ranged from gray to brown. Testing of soils using a MiniRae<sup>TM</sup> Photo Ionizing Detector (PID) indicated that approximately half of the samples had low levels of volatile organic compounds as indicated by readings in the range of 1-40 ppm (PID calibrated to benzene). Based on the absence of staining, positive fluorescence under UV light, or high PID readings, it is unlikely that the soils contained DNAPL.



Figure 2 - Generation of composite soil samples

<b>Table 1 - Bulk samples for laboratory studies</b>			
Subsample	Approximate Weight (lbs)	Handling	Storage
1) Composite Soil Properties	~ 10 lbs	Weighed and subsequently dried at 105°C.	Tupperware at room temperature
2) ZVI-Clay Efficacy	~ 10 lbs	Mixed in a blender with 1% clay by weight and water to yield a consistency similar to that anticipated in the field after treatment.	Tupperware with minimal head space at ~ 4°C
3) DNAPL Distribution Post Mixing	~ 30 lbs	Weighed and subsequently dried at 105°C. (Note: This study was actually conducted using clean a white US Silica sand to enhance visualization)	5-gallon bucket at room temperature
4) Hot Air Flushing	~ 20 lbs	Mixed in a blender with water to yield a consistency similar to that anticipated in the field after treatment.	5-gallon bucket at room temperature at ~ 4°C
5) Post Mix Studies	~20 lbs	Weighed and subsequently dried at 105°C.	Tupperware at room temperature
6) Archive	~30 lbs	Weighed	5-gallon bucket at room temperature

## 2.2 Physical Properties of the Composite Soil Samples

Table 2 summarizes physical properties and associated methods used to characterize the composite soils. Results from these, and all subsequently described studies, are presented in Section 3 of this report.

<b>Table 2 - Physical properties and associated analytical methods</b>	
Property or Characteristic	ASTM Test Standard
Moisture Content	D 2216
Liquid Limit, LL	D 4318
Soil Density	D 1587
Plastic Limit, PL	D 4318
Plasticity Index, PI	D 4318
Particle Sizes: gravel (4.75-76.2 mm) sand (0.075-4.75 mm) silt (0.002-0.075 mm) clay (< 0.002 mm)	D 422
Classification (USCS)	D 2487

### 2.3 ZVI – Clay Efficacy

Efficacy of the ZVI-Clay treatment was evaluated by mixing contaminated site soils with 1% bentonite clay and varying amounts of granular iron as shown in Table 3 and Figure 3. The samples were prepared on September 3<sup>rd</sup>, 2004. The 20 mL test vials were extracted at 3, 7, 14, 31, and 59 days. Analysis included:

- Perchloroethene (PCE)
- Trichloroethene (TCE),
- 1,1- Dichloroethene (1,1-DCE),
- cis-Dichloroethene (cis-DCE),
- Trans-Dichloroethene (trans-DCE),
- Vinyl-Chloride (VC),
- Chloride (Cl<sup>-</sup>)

Analytical methods are described in Appendix B. In addition, four 31-day samples were sent to a commercial laboratory as a quality control check and to obtain a complete VOC analysis. Properties of the bentonite, Peerless<sup>TM</sup> iron and GMA<sup>TM</sup> iron are presented in Table 4.

Table 3 - ZVI clay unspiked study matrix						
Reactive Media	3 days (CSU)	7 days (CSU)	14 days (CSU)	31 days (CSU)	31 days (Outside lab)	59 Days
0% Fe	CC-0-3	CC-0-7	CC-0-14	CC-0-28	-	CC-0-59
1% Peerless Fe	S-1P-3	S-1P-7	S-1P-14	S-1P-28	-	S-1P-59
3% Peerless Fe	S-3P-3	S-3P-7	S-3P-14	S-3P-28	S-3P-28L	S-3P-59
5% Peerless Fe	S-5P-3	S-5P-7	S-5P-14	S-5P-28	-	S-5P-59
7% Peerless Fe	S-7P-3	S-7P-7	S-7P-14	S-7P-28	-	S-7P-59
1% GMA Fe	S-1G-3	S-1G-7	S-1G-14	S-1G-28	-	S-1G-59

Table 4 - Properties of stabilizing agent and reactive media	
WYO-BEN Hydrogel Bentonite Clay	
Particle Size (ASTM D 1140)	80 % minus #200 sieve (75 µm)
Surface Area	82 m <sup>2</sup> /g (external), 800 m <sup>2</sup> /g (all surfaces)
Screen Residual Retained	4.0 % retained on #200 sieve
pH @ 5 % suspension	9.1
Moisture Content	<10%
Peerless Iron	
Particle Size (U. S. Standard Sieve Sizes)	Minus #50 (300 µm) to Plus #100 (150 µm)
Total Density	5.83 g/cm <sup>3</sup>
Surface Area	3.82 m <sup>2</sup> /g
GMA Iron	
Particle Size (U. S. Standard Sieve Sizes)	~ Minus #50 (300 µm)
Total Density	6.83 g/cm <sup>3</sup>





**Figure 3 - Preparation of ZVI-Clay efficacy samples A) Homogenizing soil iron and clay in applicator, B & C) Sample extrusion into 20 mL glass vials, and D) samples with Teflon™ septa and aluminum crimp tops.**

A concern that developed during preparation of the Table 3 samples was that background contaminant levels (post handling) might be insufficient to effectively resolve ZVI-Clay performance. In recognition of this concern, additional testing was conducted using samples spiked with site DNAPL to achieve a PCE concentration of ~100 mg/kg. This was accomplished using a micro syringe to inject small droplets of the site DNAPL followed by repeated cycles of vigorous mixing at 15-minute intervals for a period of 2-hours. Using the spiked soils, the Table 5 study matrix was developed and subsequently analyzed per the methods described above for the Table 3 samples.

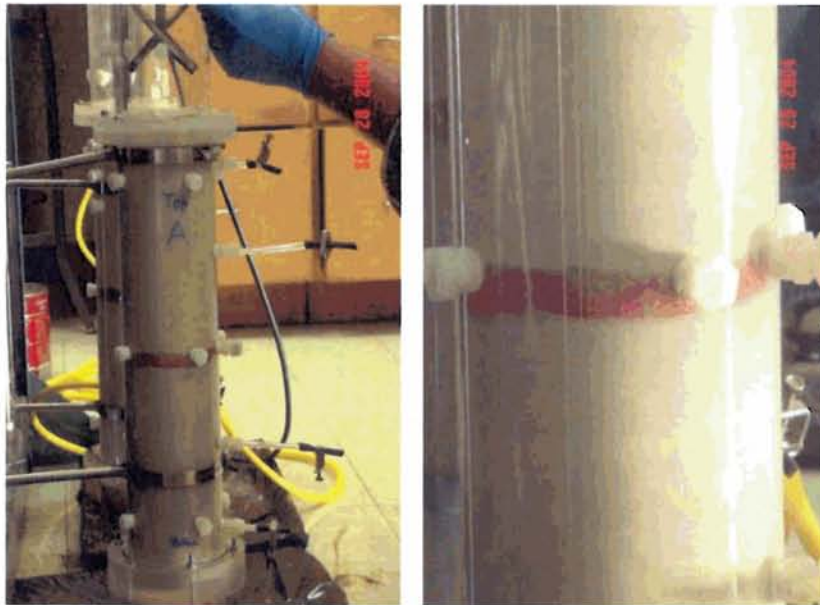
Table 5 - ZVI clay spiked study matrix							
Reactive Media	3 days (CSU)	7 days (CSU)	14 days (CSU)	31 days (CSU)	31 days (Outside lab)	59 Days (CSU)	
0% Fe	NS-0-3	NS-0-7	NS-0-14	NS-0-28	NS-0-28L	NS-0-59	
1% Peerless Fe	NS-1P-3	NS-1P-7	NS-1P-14	NS-1P-28	NS-1P-28L	NS-1P-59	
3% Peerless Fe	NS-3P-3	NS-3P-7	NS-3P-14	NS-3P-28	NS-3P-28L	NS-3P-59	
5% Peerless Fe	NS-5P-3	NS-5P-7	NS-5P-14	NS-5P-28	-	NS-5P-59	
1% GMA Fe	NS-1G-3	NS-1G-7	S-1G-14	S-1G-28	-	NS-7P-59	

## 2.4 DNAPL Distribution Post Mixing

As a complement to the ZVI-Clay efficacy studies, three identical columns (A,B, and C) were prepared with a 10 mL PCE pool at the midpoint (Figure 4) on September 27, 2004. To improve visualization of the mixing a white fine-grained laboratory sand (US Silica –95 mesh) was used instead of site soil. In addition, a ~ 2 cm coarse sand layer (Colorado Silica 18-40) was placed at the midpoint of the column for emplacement of the DNAPL. Ten mL of laboratory grade PCE dyed red with Sudan IV was injected into the coarse sand layer via a septa in the wall of the column using a syringe.

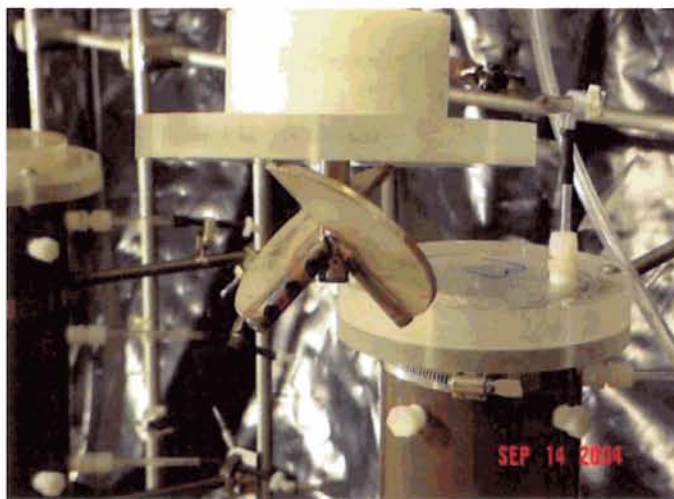
The objective of this study was to investigate the effect of ZVI-Clay and soil mixing on a DNAPL pool. For all three columns, an initial downward mixing pass was completed in which 640 mL of iron–bentonite slurry was injected. The slurry contained 38 g of bentonite and 91 g of Peerless iron. This yielded approximately 1 and 3 percent bentonite and iron per dry weight soil, respectively. Mixing was accomplished using the tool shown in Figure 5. The mixing tool was rotated at approximately 25 rpm and was advanced through approximate 1 inch intervals every 30 seconds.

Column A involved a single pass in and out of the column. Column B involved two passes in and out of the column. Column C involved an attempt to complete three passes. Unfortunately, only the first pass was completed due to failure of the mixer drive system. At the conclusion of mixing the apparent expansion of the soil column was recorded.



**Figure 4 - Plexiglas column (inner diameter 10 cm, length 46 cm) filled minus 95 mesh Ottawa and a ~ 2m coarse sand layer filled with PCE DNAPL dyed red with Sudan IV**





**Figure 5 - Mixing blade detail. The iron clay slurry is injected down the shaft and exits through the port at the backside of the mixer.**

Following mixing, columns A and B were sampled on October 7, 2004. A composite sample was collected from Column A. This was acquired by driving a thin-walled brass tube through sediments along the axis of the column. In addition, ten perpendicular subcores were collected perpendicular to the axis from Column B at approximate 5 cm intervals. This was accomplished by driving thin wall brass tubes through ports in the side of the column. After collection, all samples were placed in MTBE for extraction of organic compounds and subsequently analyzed following Appendix B procedures. The sampling procedures are illustrated in Figure 6.



**Figure 6 - Sampling procedures for DNAPL distributions studies; i) composite along axis of column A and ii) ten discrete sub samples from points along column B.**



## 2.5 Hot Air Flushing

An approach under consideration for Site 88 is soil mixing with hot air injection prior to delivery of ZVI-Clay. To evaluate this option, three Plexiglas columns were loaded with site soils spiked with ~ 100 mg/kg PCE. Spiking was accomplished using a micro syringe to inject small droplets of the site DNAPL into ~ 30 kg of soil followed by repeated cycles of vigorous mixing at 12 hour intervals over a period of three days. The three columns include:

- A) No treatment control
- B) Hot air flushing (one pass) prior to delivery of ZVI-Clay (one pass)
- C) ZVI-Clay only (one pass)

The columns were loaded and mixed on September 14, 2004. Mixing followed the procedure described for the DNAPL Distribution studies. Post mixing, the columns were stored in a dark cabinet until October 7, 2004 when soil samples were collected from similar locations in each column following the techniques shown in panel B of Figure 6. After collection, all samples were placed in MTBE for extraction of organic compounds and subsequently analyzed following Appendix B procedures. The experimental setup for the hot air flushing studies is illustrated in Figure 7. At the conclusion of mixing the apparent expansion of the soil column was recorded.



**Figure 7 - Hot air flush studies A) Columns A, B, and C prior to mixing B) Column B with hot air injection set up including continuous air monitoring with a MiniRae™ PID and gas collection in a 20L Tedlar™ sample bag.**

## 2.6 Post Mix Sediment Properties

Table 6 presents parameters and methods used to characterize the physical properties of treated soils. Based on preliminary interpretation of the hydraulic conductivity and contaminant depletion data, CH2M HILL decided to conduct these tests using 1 and 2 percent bentonite and Peerless iron, respectively, per dry weight soil.

Table 6 - Bulk composite properties	
Parameter	Method
Compressive Strength	ASTM D1633 (CHECK)
pH	API RP 13B-1
Hydraulic Conductivity at 0 and 1% Bentonite Clay	ASTM D5084
Soil Expansion with Mixing	Under Development

## 2.7 Grout Mix Studies

In-situ soil mixing (ISS) equipment injects reagents in the form of a liquid grout. The grout must suspend the reagent (granular iron) for transfer through the equipment and into the soil, and satisfy the functions of a drilling fluid. The grout must be pumped through a long hose, up the drilling rig (often as high as 100 ft above the ground surface), through a swivel, through the Kelly bar, and finally be injected deep into the subsurface with sufficient pressure to exit the equipment without plugging the injection nozzles. It is therefore critical that the grout satisfies both suspension and workability requirements, and performs these functions with minimal difficulties. The amount of clay and iron added is controlled by the total amount of grout added during mixing.

Several grouts were formulated and tested in the laboratory to better define the composition of the ZVI-Clay grout. The ZVI-Clay grout generally consists of water, clay, and ZVI. Three clays were tested; air float kaolin, polymer amended kaolin, and 90 bbl/ton (API grade) bentonite clay. The clay serves several important functions in the ZVI-Clay grout including the following:

- Suspends the granular iron in a grout for efficient injection,
- Acts as the drilling fluid to facilitate penetration and mixing of the ISS equipment,
- Lowers the permeability of the treated materials, and
- Contributes to the cost of construction.

Laboratory studies were performed with the three clays mixed with tap water, with and without granular iron. First, in order to quantify the ability of the clay to suspend the granular iron, the viscosity of the clay/water slurry was measured at different proportions, with a Marsh Funnel. After mixing the clay/water slurry with



ZVI, visual observations were made of the suspension, and the amount of settlement was noted. Greater viscosity is generally indicative of greater capability to suspend solids (i.e. granular iron). The density of the ZVI/Clay grout was measured with a mud balance to check clay and iron proportions. The pH and temperature of selected grouts were also measured. All test methods comply with API RP-13B-1 as noted in Table 7.

Table 7 - Slurry properties	
Viscosity	API RP 13B-1
Density	API RP 13B-1
pH	API RP 13B-1

### *2.8 Cement Stabilization*

After the soil is treated with the ZVI-Clay grout, expansion of the soil and additional water may make the surface too soft and weak to support future activities. In order to quickly and economically stabilize the surface, dry Portland Type I-II cement is distributed onto the surface and mixed into the top few feet with the ISS rig. With time, natural consolidation will allow the excess water to seep away or evaporate, so the cement treatment is generally used only on the surface and as a temporary measure.

Soil treated with the ZVI-Clay grout was mixed with dry cement at 4 to 8% by total weight. Portland cement with Test cylinders were made and tested for unconfined compressive strength (UCS) after 7 and 28 days of curing in accordance with ASTM D1633.



### 3 RESULTS

The following presents results from the studies introduced in Section 2.

#### 3.1 Physical Properties of Bulk Soil Samples

Table 8 presents properties of the composite soil used in the laboratory studies. Consistent with the soil description presented in Appendix A, the composite soils consist of fine sand and silt with clay. Figure 7 presents the results of a grain size analysis.

Table 8 - Summary of physical properties of composite sample of site soils.		
Property or Characteristic	ASTM Test Standard	Test Result
Moisture Content (wt %)	D 2216	36.5
Liquid Limit, LL (%)	D 4318	28
Plastic Limit, PL (%)	D 4318	19
Plasticity Index, PI (%)	D 4318	9
Particle Sizes: gravel (4.75-76.2 mm) sand (0.075-4.75 mm) silt (0.002-0.075 mm) clay (< 0.002 mm)	D 422	0 42 42 16
Classification (USCS)	D 2487	CL
Soil Density (dry) gm/cm <sup>3</sup>	D 1587	1.3
Soil Density (saturated) gm/cm <sup>3</sup>	D 1587	1.8

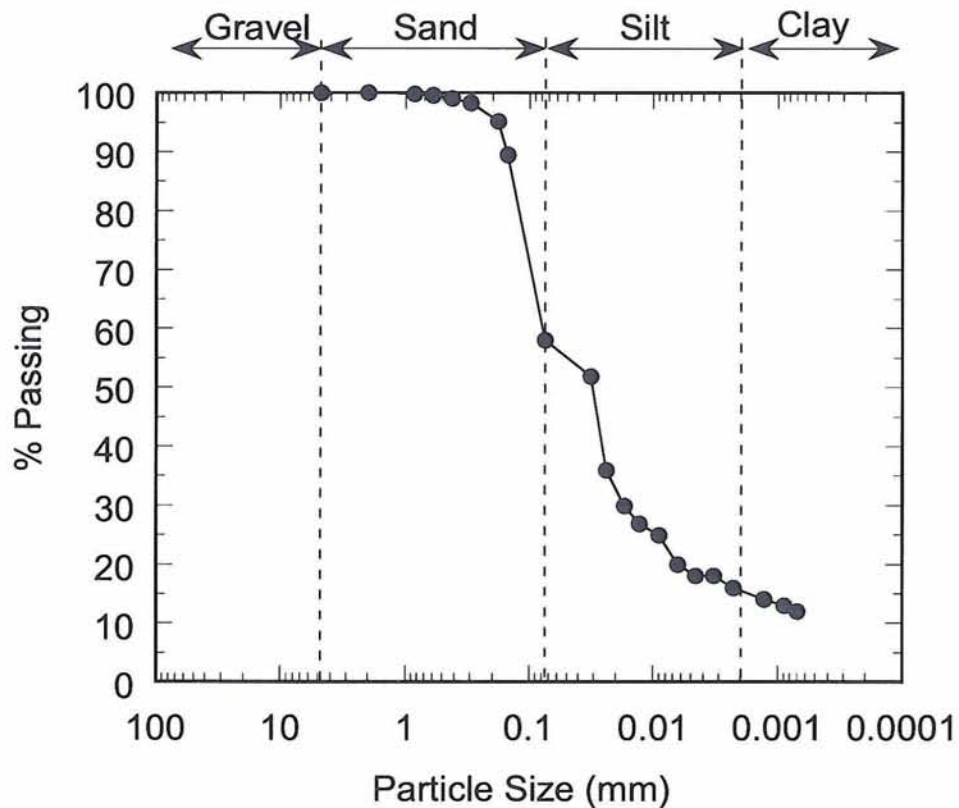


Figure 8 - Grain-size curve for composite sample of site soils. (specific gravity of the sediment is assumed to be 2.65).

A central issue with ZVI-Clay treatment is the hydraulic conductivity of the mixed soils. Reduced hydraulic conductivity in the source zone provides multiple potential benefits including:

- Reduced groundwater flow through the source zone.
- Increased time for degradation of target compounds to proceed.
- A reduction in the inflow of electron acceptors that could reduce the longevity of the iron (e.g. oxygen in groundwater).

Building on Figure 9 and Figure 10, the hydraulic conductivity of the untreated and treated composite materials are  $5 \times 10^{-7}$  and  $3 \times 10^{-8}$  cm/sec, respectively. These values are 3 and 4 orders of magnitude lower than the reported field hydraulic conductivity of the transmissive portion of the source zone of  $5 \times 10^{-4}$  cm/sec reported in CH2M HILL (2004). Note the low hydraulic conductivity of the composite soil without the bentonite clay reflects the effect of homogenization of the interbeds of sands, silt, and clay.

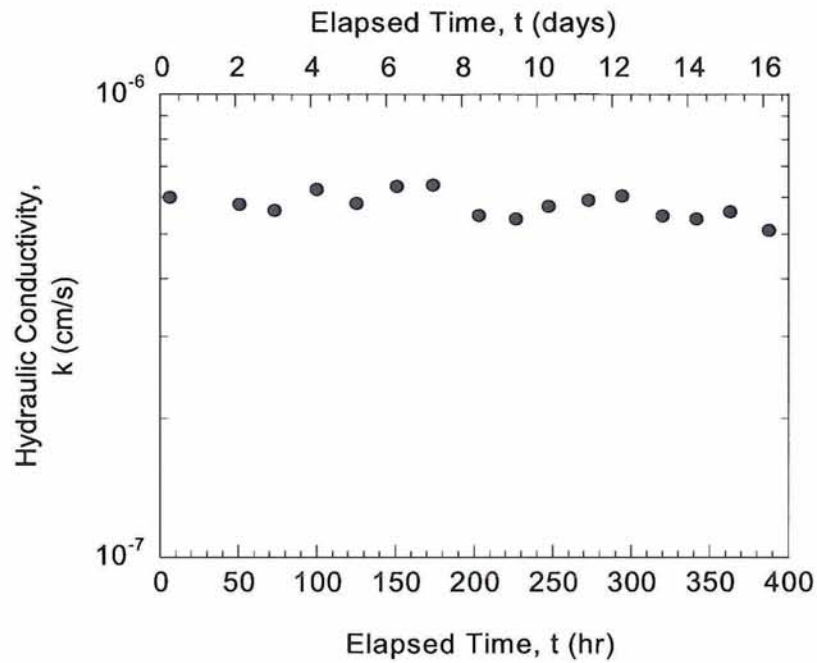


Figure 9 - Hydraulic conductivity versus elapsed time for untreated composite sample (falling head permeameter test).

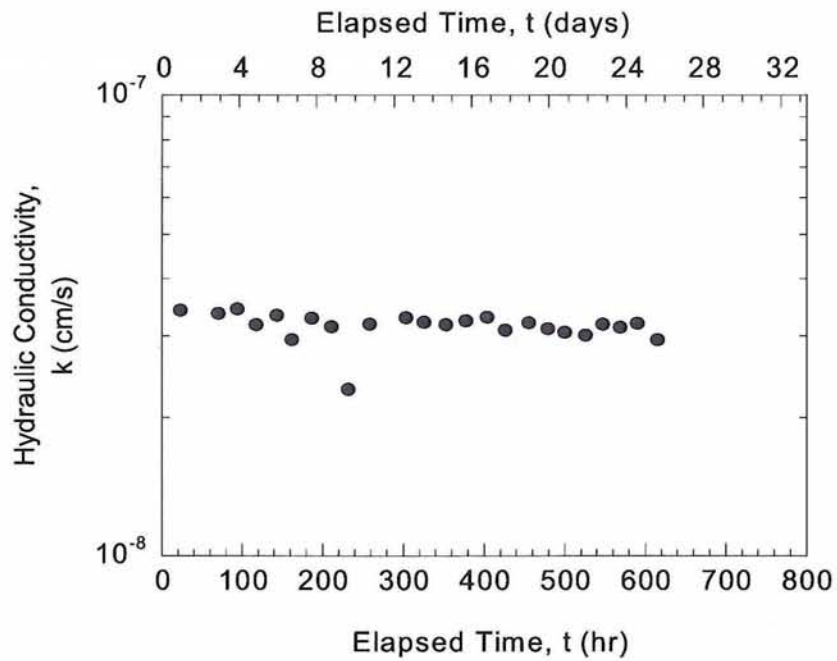


Figure 10 - Hydraulic conductivity versus elapsed time for composite sample treated with 2 % iron and 1 % bentonite clay (by dry weight of *in situ* soil, falling head permeameter test).



### 3.2 ZVI-Clay Efficacy

Results presented in this section demonstrate the potential effectiveness of the ZVI-Clay technology to degrade PCE and associated products at Site 88. The primary metrics of performance are soil concentrations at 59 days and percent reduction of target compounds based on

$$\text{percent reduction} = 100 \left[ 1 - \frac{C_{i,t}}{C_{i \text{ control},t}} \right]$$

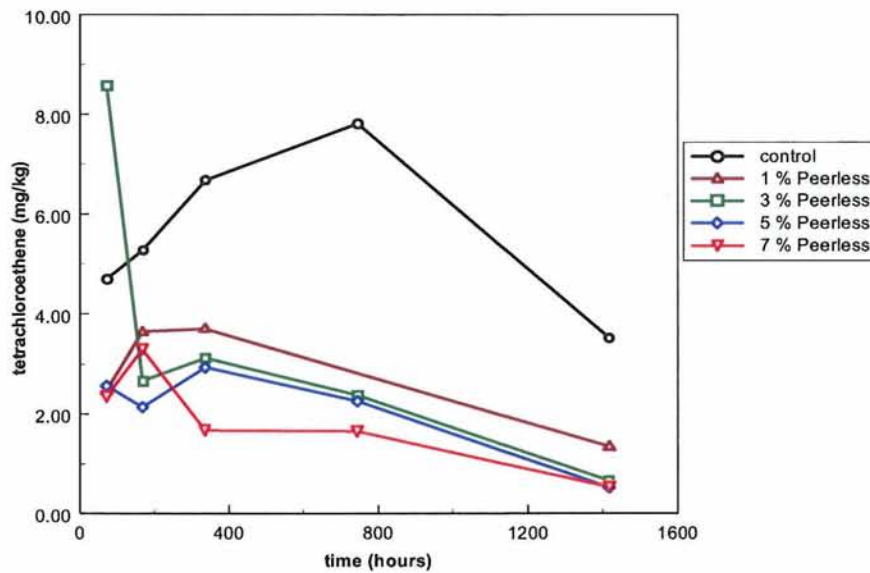
Where:

$C_{i,t}$  = concentration of constituent  $i$  (e.g. PCE) in the treated reaction vial after  $t$  days

$C_{i \text{ control},t}$  = concentration of constituent  $i$  (e.g. PCE) in the control reaction vial after  $t$  days

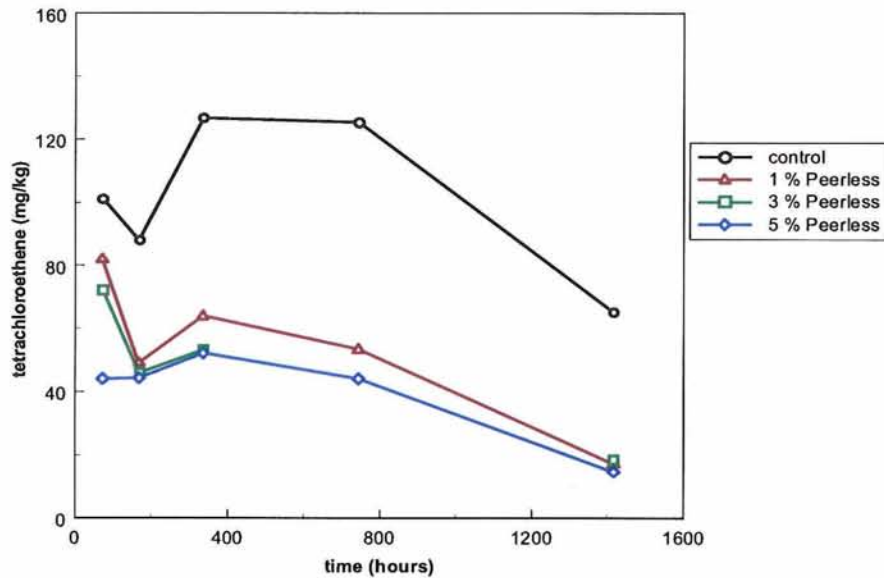
#### 3.2.1 Target Compound Degradation

Figure 11 presents PCE concentrations as a function of time for unspiked soils including the control and samples with 1, 3, 5, and 7 % Peerless<sup>TM</sup> iron. Note all samples contain ~ 1% bentonite clay by dry weight soil. Comparing treated samples to the control, percent reduction at 59 days is in the range of 81%. It is important to note that the degradation fractions are similar for the 3,5, and 7% Peerless iron application rates, suggesting that reactive iron is present in abundance relative to demand. Variability in the control samples with time is attributed to 1) variations in the initial concentration of the samples and 2) apparent transformation of PCE to TCE via biotic and/or abiotic reactions with soil-bentonite control media.



**Figure 11 - PCE concentrations in the unspiked study versus time.**

Figure 12 presents PCE concentrations as a function of time for spiked soils including the control and samples with 1, 3, and 5 % Peerless<sup>TM</sup> iron. Note all samples contain ~ 1% bentonite clay by weight and the control concentrations are a factor of ~20 times greater than the unspiked samples. Comparing treated samples to the control; percent reductions at 59 days are in the range of 71-75%. Treatment does not appear to be strongly dependent on iron application rate, since the soil concentrations are similar at 59 days between the three application rates.

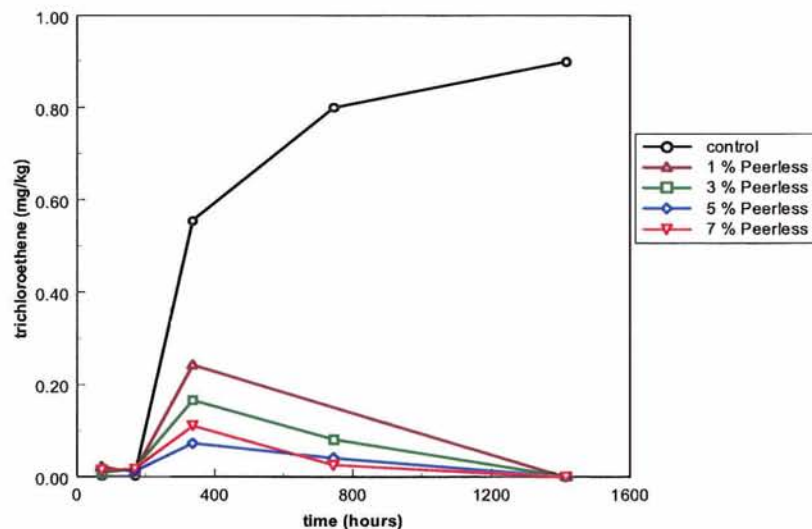


**Figure 12 - PCE concentration as a function of time in the spiked study**

### 3.2.2 Products of PCE Degradation

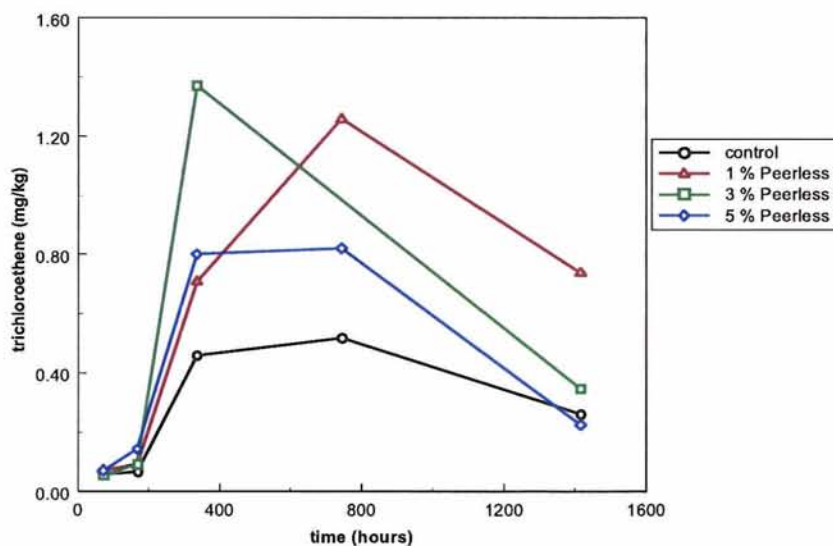
Two common degradation pathways for PCE are 1) sequentially reductive dechlorination producing TCE, DCE, VC and chloride and 2) Dihalo elimination producing dichloroacetylene, chloroacetylene, and acetylene. Figure 13 presents TCE concentrations as a function of time for unspiked soils. The control samples indicate a trend of increasing TCE concentration with time that reach a maximum of ~ 10 % of the initial unspiked PCE concentration at 59 days. This is attributed to sequentially reductive dechlorination of PCE due to reactions with the soil and/or bentonite clay. Much lower concentrations of TCE are observed for the treated soils (~ 0-1% of initial PCE concentrations). This is attributed to rapid degradation of TCE in the presence of the iron.





**Figure 13 - TCE concentration as a function of time in the unspiked study**

Figure 14 presents TCE concentrations as a function of time for spiked soils. In this case both the control and the treated samples indicate low levels of TCE that decay with time. A key aspect of this graph is that TCE is not accumulating in the treated samples. This suggests that the kinetics of TCE degradation is much faster than PCE degradation.



**Figure 14 - TCE concentration as a function of time in the spiked study.**

Following the reductive dechlorination pathway TCE degrades to DCE. Possible isomers include 1,1-DCE, cis-DCE and trans-DCE. Of these compounds only cis-DCE was detected. Figure 15 and Figure 16 indicates that maximum cis-DCE concentration was observed at seven days. Concentrations of cis-DCE are below detection limits after seven days. As with TCE, a lack of DCE accumulation supports fast degradation relative to the rate of degradation of the parent compound (PCE). No VC was detected in any of the samples.

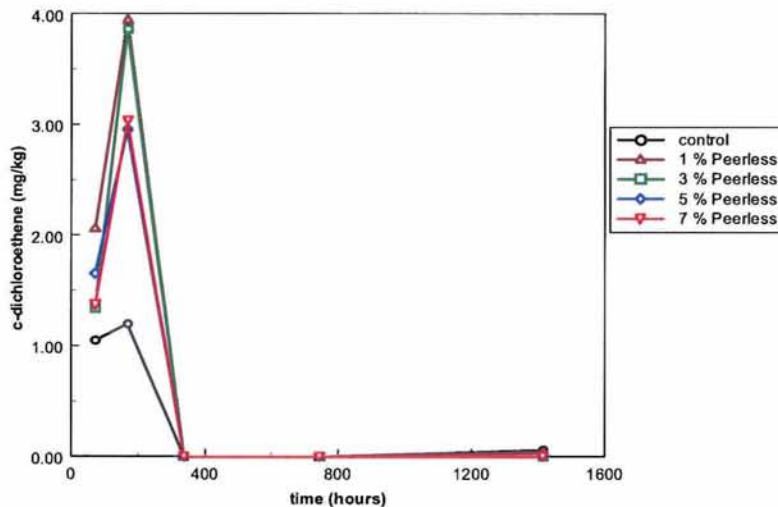


Figure 15 - cis-DCE concentration as a function of time in the unspiked study.

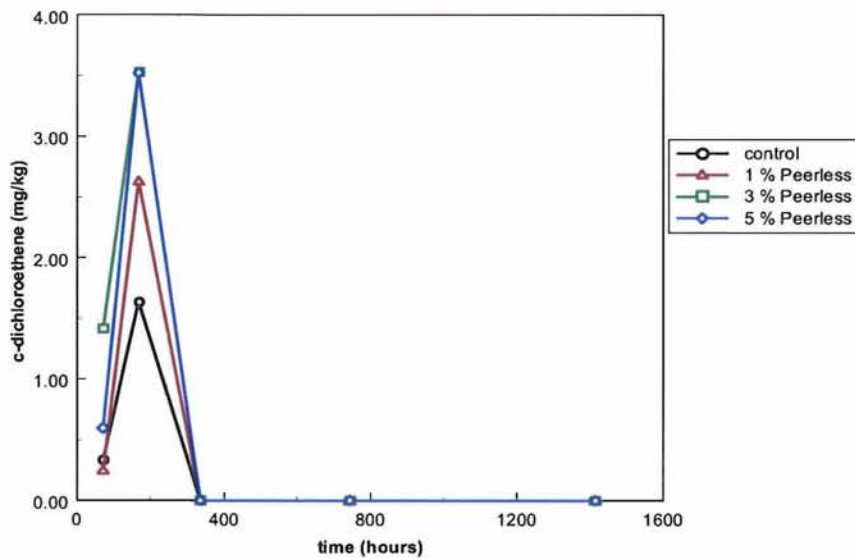


Figure 16 - c-DCE concentration as a function of time in the spiked study.

Dechlorination of PCE and its daughter compounds produces chloride. Figure 17 (unspiked) and Figure 18 (spiked) present chloride concentrations in control and treated samples as a function of time. Neither the unspiked or spiked treated soils show a significant increase in chloride relative to the control.

In the case of the unspiked samples (Figure 17), this may be explained by the fact that complete dechlorination of the initial PCE would have produced ~4 mg/kg chloride. This is a small number relative to the background chloride value of ~30 mg/kg. More likely, the apparent lower chloride values in the treated samples suggest there may be analytical interference associated with hydroxide ion.

In the case of the spiked samples (Figure 18), maximum chloride generation would be on the order of 60 mg/kg. This would have doubled the background chloride levels of ~30 mg/kg. The absence of chloride is attributed to limitations of the ISE method including potential analytical interference associated with hydroxide ion.

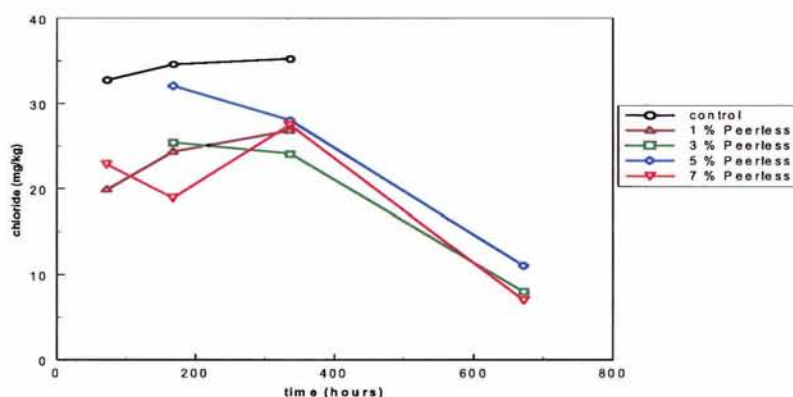


Figure 17 - Chloride concentration over time in the unspiked study.

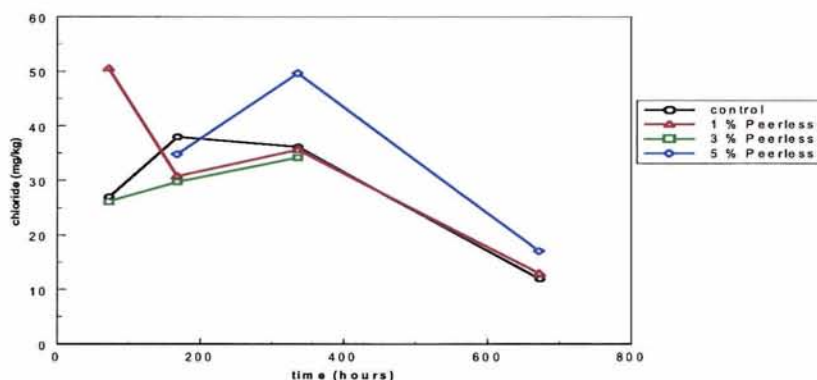


Figure 18 - Chloride concentration over time in the spiked study.



### 3.2.3 Comparison of Iron Types

Two iron types were tested during the unspiked and spiked studies, Peerless™ and GMA™. The comparison was made using 1% iron and 1% bentonite, per dry weight soil. Figure 19 and Figure 20 indicate both media provide similar rates of degradation and soil concentrations at 59 days. The interesting attribute of the GMA™ iron is that its cost is potentially  $\frac{1}{3}$  to  $\frac{1}{2}$  that of the Peerless™ iron. Unfortunately, there is a current concern that the GMA™ iron may contain other metals that could be a concern. Further research of this topic is needed.

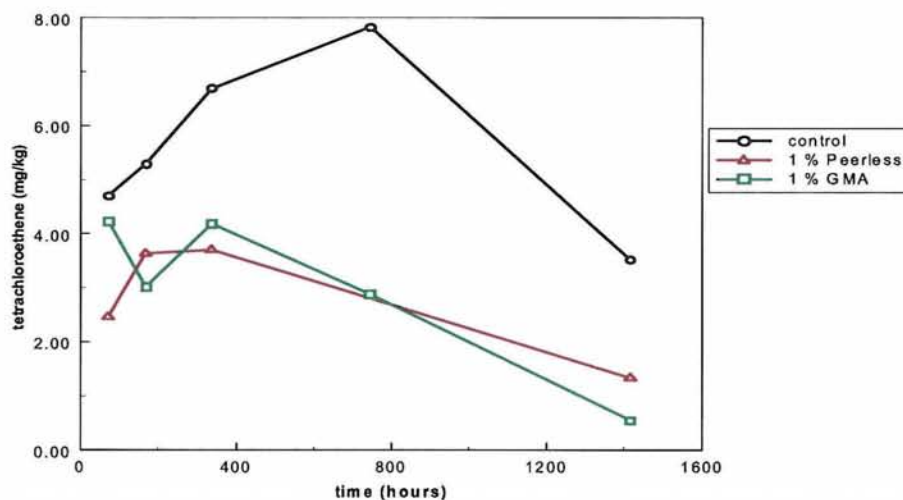


Figure 19 - Comparison of Peerless to GMA iron in the unspiked study.

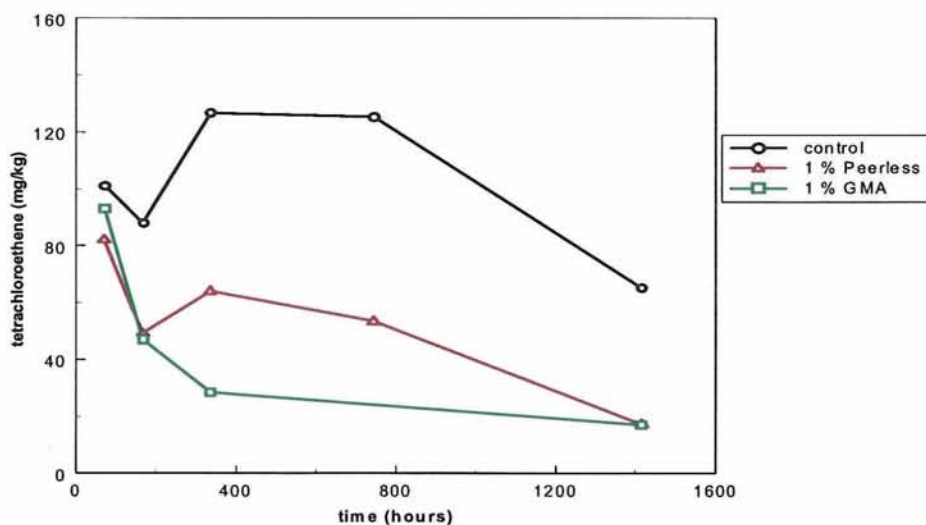


Figure 20 - Comparison of Peerless to GMA iron in the spiked study.

### 3.2.4 Reaction Kinetics

Reaction kinetics for the dechlorination of PCE was calculated using pseudo-first order assumptions and the conservative assumption that the concentration at time zero was equal to the mean concentration measured in the control vials. The calculations indicated that the rate of reductive dechlorination was not highly dependent on iron application rate (Table 9). As a point of comparison, Wadley (2004) describes PCE half lives of 16 days based on auger column tests using 10% iron and bentonite clay. These studies were conducted at Canadian Forces Base Borden, Canada.

**Table 9 - Reaction rate constants and approximate half lives based on laboratory data.**

<b>treatment</b>	<b>k</b>	<b>t<sub>1/2</sub> (hr)</b>	<b>t<sub>1/2</sub> (d)</b>
unspiked 1%	0.000	1033	43
unspiked 3%	0.001	465	19
unspiked 5%	0.001	539	22
unspiked 7%	0.001	517	22
unspiked 1%	0.001	484	20
spiked 1%	0.001	664	28
spiked 3%	0.000	787	33
spiked 5%	0.001	699	29
spiked 1% GMA	0.001	621	26

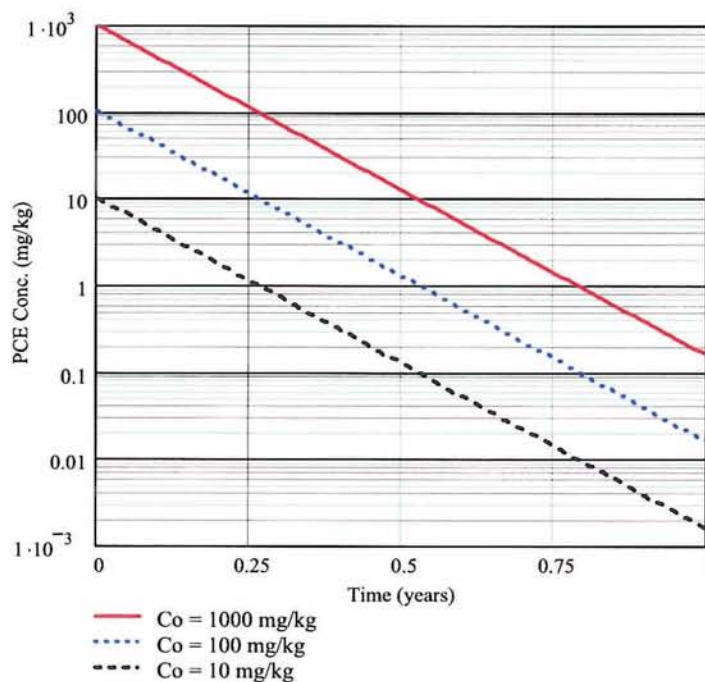
### 3.2.5 Iron Remaining

A primary concern in applying the above half lives to project performance is the assumption that reactive iron remains to degrade the contaminants. Table 10 presents the initial and 59 day iron amounts from unspiked samples with 1,3, 5, and 7% Peerless<sup>TM</sup> iron. In the 59-day study period iron losses range from 24 to 38%. The apparent losses of iron are potentially attributable to a number of factors including 1) limitation of the magnetic separation method, 2) errors in the actual amounts of iron added, and 3) actual losses due to conversion of ZVI to non-magnetic forms of iron. The longevity of reactive iron in ZVI-Clay projects is an active research topic at CSU.

<b>Table 10 - Iron remaining after 59 days</b>		
<b>Initial (percent iron per dry weight soil per initial loading)</b>	<b>59 Day (percent iron per dry weight soil)</b>	<b>% Change over 59 days</b>
1 %	0.76%	24%
3%	1.86%	38%
5%	3.99%	20%
7%	4.58%	35%

### 3.2.6 Long-Term Performance

The available data suggests that the primary process of concern is the disappearance of PCE. If in fact the reactions are proceeding as  $\text{PCE} \rightarrow \text{TCE} \rightarrow \text{DCE} \rightarrow \text{VC}$ , the rates of the subsequent steps are sufficiently fast that they are not a primary concern. Alternatively PCE degradation may be following a di halo elimination reaction pathway through acetylene. In either case, a first order projection of concentration versus time in the treated source can be developed by assuming first order kinetics, a constant reactivity of iron in the period of interest, and an initial concentration. The results of this analysis are presented in Figure 21. Note these assumptions may not fit field conditions as such; the projections are in no way a certain estimate of actual performance.



**Figure 21 - Projected PCE concentrations assuming first order kinetics, constant iron reactivity, and  $k$  of  $0.001 \text{ hr}^{-1}$**



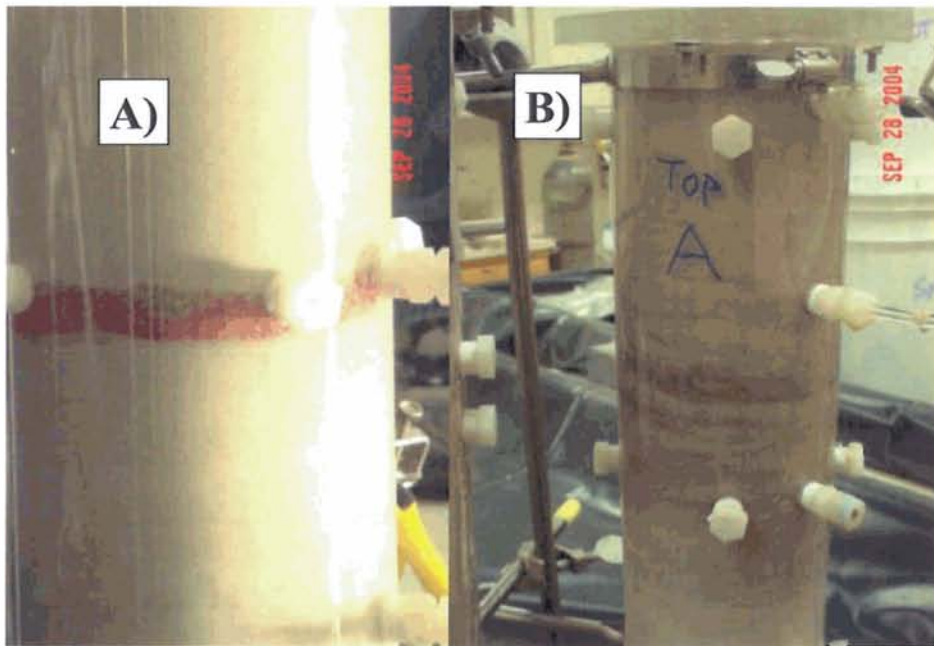
### *3.3 DNAPL Distribution Post Mixing*

Results from the DNAPL mix simulation consist of photos and quantitative soil analyses. Figure 22 Frame A) illustrates the initial condition of a ~2 cm laboratory grade PCE DNAPL pool dyed red. Figure 22 Frame B) illustrates the post mix condition (~ time =0) after two passes.

The immediate effect of mixing was to disperse the DNAPL primarily upward over an interval of ~ 20 cm. The contiguous DNAPL in the pool became sparse ganglia of DNAPL surrounded by clay and zero valent iron. This was followed by the surprising result that nearly all of the dispersed DNAPL ganglia disappeared in period of a less than 1 week. Our best explanation is that the combination of 1) dispersing the DNAPL into isolated ganglia and 2) surrounding these ganglia by reactive media produced large concentration gradient that drove rapid dissolution of the DNAPL. This promising result will likely be the focus of further research at CSU.

Other observations from this effort include:

- 1) Two passes produced greater DNAPL dispersion and a more uniform apparent distribution of iron and clay.
- 2) Due to the upward draw of the soil auger, DNAPL was primarily pulled upward. Our original concern of downward mobilization was not observed.
- 3) The post mix column height was approximately 15 % greater than the soil column height.
- 4) PID readings in excess of 100 ppm were detected in the head space above the soil post mixing



**Figure 22 - A) pre-mixing DNAPL lens, and B) post-mixing (two passes)**

Figure 23 and Figure 24 present concentrations PCE and TCE based on analysis of soils core drawn from the mixed columns after 16 days. The original concentration of PCE in the pool was on the order 60,000 mg/kg. For both the discrete and vertical composite samples there is an apparent ~ 50 % depletion of PCE. This is consistent with the apparent half life of PCE observed in the ZVI-Clay efficacy studies. TCE production described in Figure 24 is minor and consistent with results from the ZVI-Clay efficacy studies.

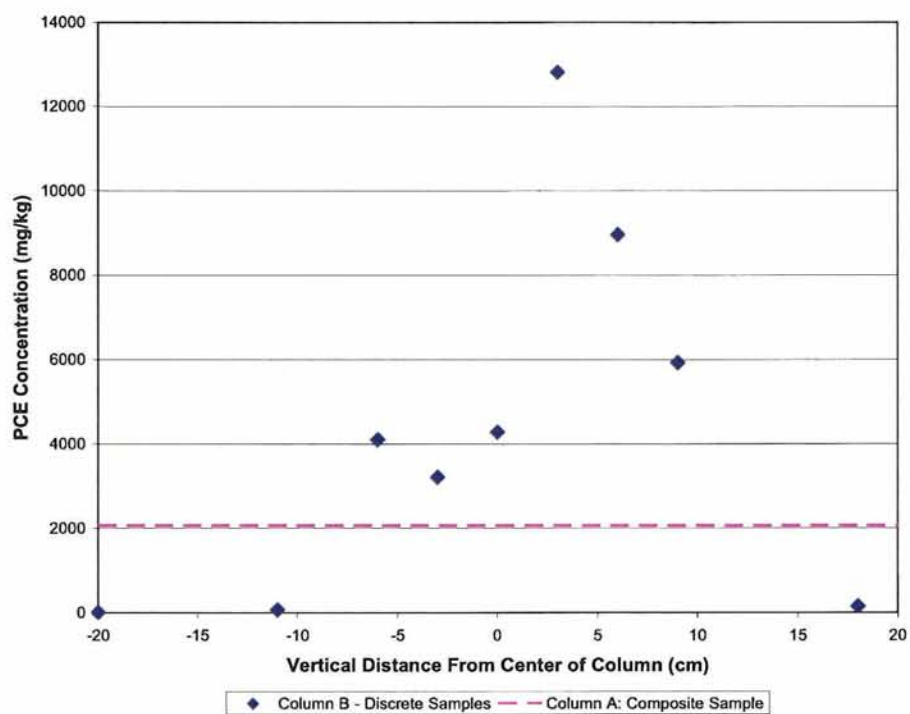


Figure 23 - Post-mixing PCE distribution.

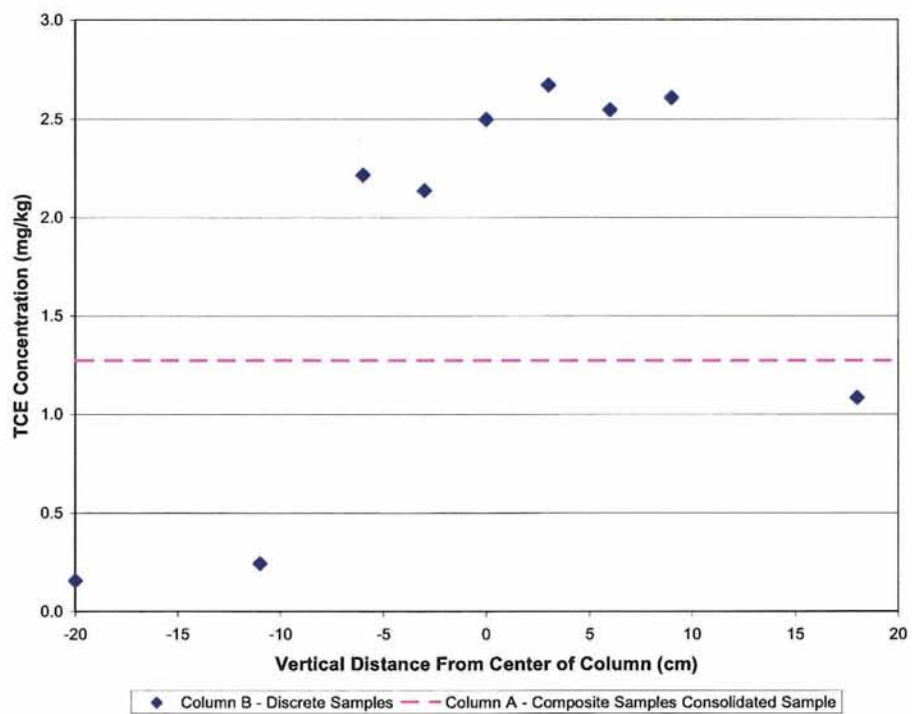


Figure 24 - Post-mixing TCE distribution.



### 3.4 Hot Air Flushing

Figure 25 presents results from the hot air flush study. The primary result is that little difference in soil concentration is seen 23 days with and without a hot air preflush. Observations made during the simulation suggest that the primary limitations of hot air flushing are 1) the small heat content of hot air and 2) production of gas with PID readings in excess of 100 ppm. As with the DNAPL mix studies, apparent PCE depletion rates are similar to that observed in the ZVI-Clay efficacy studies.

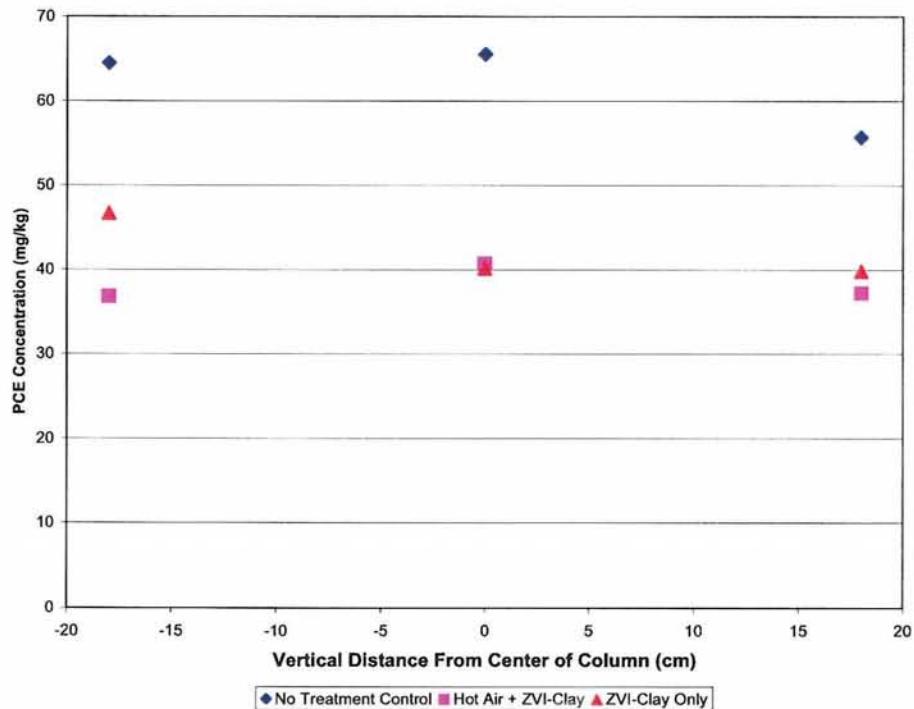


Figure 25 - PCE concentration measured after 23 days following mixing simulation

### 3.5 Post Mix Sediment Properties

The properties of treated soils, containing 1 % bentonite and 2 % Peerless iron by dry weight, are presented in Table 11.

Table 11 - Properties of the treated soils	
Parameter	Result
Unconfined Compressive Strength	96 psi @28 days
pH	7-8
Hydraulic Conductivity	$5 \times 10^{-6}$ cm/sec
Estimated Soil Expansion	15-25 %

### 3.6 Grout Mix Studies

Clay/water slurries were tested with the proportions and results noted in Table 12

Table 12 - Grout mix results				
	Clay/Water Ratio (by weight)	MF Viscosity (seconds)	Density (pcf)	PH (units)
Air Float Kaolin	0.05	27	64.3	
	0.10	29	66.1	
	0.15	33	68.6	
	0.20	45	71.1	
	0.25	>90	73.6	
Polymer Amended Kaolin	0.064	27	64.5	7
	0.26	27		
	0.40	28		
	0.52	28	78.5	7
API Bentonite	0.06	44	64	8
	0.075	62	65	8

Air float kaolin is clearly inferior to bentonite as an efficient suspension agent. Polymer amended kaolin performed better than air float kaolin, but at proportions that are about 4 times the clay required with bentonite. In addition, bentonite is well known for its ability to lower the permeability of soils at small addition rates, and kaolin is generally less effective at lowering soil permeability. Furthermore, bentonite suspends the ZVI at least as well as the kaolin (either type), but at

much lower addition rates, and thus at a much lower cost in both materials and construction. Due to the clear superiority of bentonite in performance and its much lower cost, bentonite was selected for use in the ZVI-Clay grout.

The amount of ZVI required may vary depending on the application rate required for contaminant treatment. As presented in Table 13, two grouts were made and tested to gauge the approximate limits of bentonite clay to suspend ZVI.

Table 13 - Results from grout studies			
	6% Bentonite Grout	6% Bentonite Grout	7.5% Bentonite Grout
ZVI/Water	None	None	None
MF Viscosity (sec.)	44	44	75
Density (pcf)	64.5	64.5	65
PH (units)	8.0	8.0	7.5
ZVI/Water	0.12	0.18	0.49
MF Viscosity (sec.)	45	46	>180
Density (pcf)	70	73	88.6
PH (units)	7	7	7

The 7.5% bentonite grout (B/W = 7.5%) was capable of suspending a considerable amount of ZVI, but this is much more than needed and near the limit of workability (note: MF>180 sec.). Based on these results, an optimum bentonite grout would probably include about 7% bentonite (B/W =7%), with a ZVI/Water of about 14%, with a corresponding grout density of about 72 pcf.

Finally, tests were performed to estimate the amount of ZVI and clay that could be suspended and mixed with Camp Lejeune soils (Table 14). In Mix 1, the clay/water slurry was mixed with the soils, and then the ZVI was added dry. In subsequent mixes, a ZVI/Clay/Water grout was mixed with the soils. Proportions and results are shown in the table below.

Table 14 - Properties of select mixes				
	Mix 1	Mix 2	Mix 3	Mix 4
ZVI/Clay Grout				
B/W	0.075	0.075	0.06	0.06
ZVI/W	NA	0.48	0.12	0.18
Treated Soil				
B/ Dry Soil	0.0075	0.0031	0.012	0.01
ZVI/ Dry Soil	0.05	0.0063	0.024	0.03
Water/Dry Soil	0.0925	0.05	0.17	0.16
Slump (inches)	5	2.75	6.75	5



### *3.7 Geotechnical Evaluations*

With the data produced by this report it is possible to develop a preliminary "recipe" for ISS treatment of the contaminated soil with ZVI-Clay grout. The recipe is in two parts. First, a ZVI-Clay grout must be produced. The basic proportions and properties of the grout are as follows:

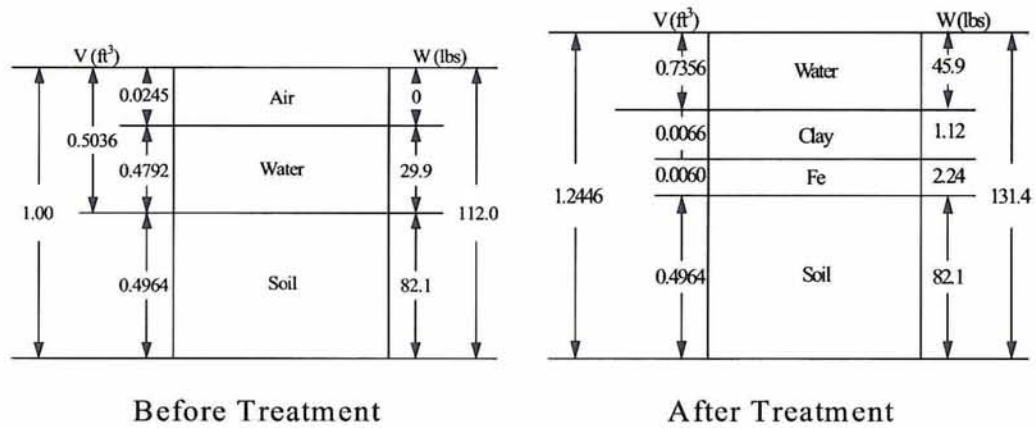
- B/W = 7%
- ZVI/W = 14%
- Grout density = 72 lbs/ft<sup>3</sup>

It is expected that the viscosity of the grout will be about 50 to 60 seconds, but this may require modification in the field.

The ZVI-Clay grout will be injected into the contaminated soil and mixed with the ISS rig. An application rate of 1% bentonite and 2% ZVI can be achieved by injecting about 42 gallons of the ZVI-Clay grout per cubic yard of soil treated.

The application rate is based on a total (wet) soil density of 117 pcf. The value 117 pcf was derived from a weighted analysis of the median density of the cores from the site. High, low, and unusual values were excluded from the values considered in the weighted median.

The addition of the ZVI-Clay grout will increase the volume of the treated soil by about 20 to 25%. Water added in the grout is the primary contributor to increasing the volume of the treated soil. Figure 26 depicts the volumetric and weight fractions of subsurface materials before and after treatment.



**Figure 26 - Volumetric and weight fractions of subsurface materials before and after treatment**

### 3.8 Cement Stabilization

Dry Portland cement (PC) was added to and mixed with the treated soils with the following unconfined compressive strength test results.

Table 15 - Cement stabilization data		
	4% PC	8% PC
UCS (psi) @ 7 days	13.0	79.8
UCS (psi) at 28 days	21.5	94.3

Based on these results, the optimum amount of PC is probably in the range of 6%. The amount of PC added may be varied depending on foundation and site access requirements.

#### **4 REFERENCES**

CH2M HILL (2004), Draft Site 88 Building 25 Source Removal Engineering Evaluation / Cost Estimate Operable Unit No.15, Contract No.N62470-02-D-3052, May

Wadley, Sharon, Robert, Gillham, and Lai Gui (2004), Remediation of DNAPL Source Zones with Granular Iron: Laboratory and Field Tests, Submitted to Journal of Groundwater. Publication anticipated Winter 2005.



## APPENDIX A – LABORATORY SOIL LOGS

Update with Densities

Camp Lejeune - Soil Cores

OVA

Wax

Cap +

Diameter

Core ID	weight (g)	length (cm)	ppm	cm	(g)	comment
1	1172.7	40.2	0	2.5	146.2	Well sorted fine sand - Gray
2	1121.7	40	0	2	141.2	Well sorted fine sand - Gray
3	1058	39	0	3	143	Well sorted fine sand - Gray
4	1005	38.5	0	3	167	Fine sand w silt - Gray
5	1017	35	5-10	1	120.5	Well sorted fine sand - Gray
6	961.5	39	0	3	149.2	Well sorted fine sand - Dark Brown
7	781.4	29	0	3	132.3	Well sorted fine sand - Dark Brown
8	1120.8	39	0-5	2	140.9	Well sorted fine sand - Gray
9	962.2	40	0	3	143.1	Well sorted fine sand - Dark Brown (piece of wood)
10	1013.8	36.5	0-10	4	178	Well sorted fine sand - Gray (with woody debris)
11	1050.4	38	5-15	6	179.2	Well sorted fine sand - Gray
12	1097	40	0-5	4	139.6	Well sorted fine sand with silt inclusions - gray
13	669	27	0	5	144	Fine sand w silt - Gray
14	608	29	0	2	117.5	Fine sand w silt - Dark Brown
15	920	39	0	2	140.5	Fine sand w silt - Gray
16	1039.6	39	0	3	133.8	Fine sand w silt - Gray to Brown
17	694	30	0	2	106	Silt w fine sand gray to brown
18	999	35	0	5	160	Silt w fine sand gray to brown (with woody material)
19	869	31	5-15	2	125	Well sorted fine sand - Gray
20	668	23	0	3	113	Well sorted fine sand - Gray
21	1093	39	5-10	3	148	Well sorted fine sand - Gray
22	982	39	0-5	3	146	Well sorted fine sand - Gray - No Fluorescence

Core ID	weight (g)	length (cm)	ppm	cm	(g)	comment
23	1023	40	0	3	150	Silt with fine sand - Brown
24	1014	41	0	4	160	Silt with fine sand - Gray - Brown
25	1063	40	0	4	151	Silt with fine sand - Gray - Brown (with woody material)
26	1007	37	10-20	5	166	Well sorted fine sand - Gray - No Fluorescence
27	928	39	0	4	168	Well sorted fine sand - Gray
28	1453	49	5-10	2	165	Well sorted fine sand - Gray
29	764	27	10-20	3	134	Well sorted fine sand - Gray - No Fluorescence
30	756	27	0-5	3	125	Well sorted fine sand - Gray
31	1058	40	0-10	7	198	Well sorted fine sand - Gray - No Fluorescence
32	1047	39	0-2	6	168	Well sorted fine sand - Gray
33	966	40	0	3	156	Silt with fine sand - Gray - Brown
34	1096	39	0	2	135	Silt with fine sand - Gray - Brown
35	1190	41	0-5	2	143	Well sorted fine sand - Gray
36	1118	39	10-30	5	168	Well sorted fine sand - Gray - No Fluorescence
37	1010	37	0	1	129	Silt with fine sand - Gray - Brown
38	1052	39	0-10	3	155	Well sorted fine sand - Gray
39	972	41	10-20	11	174	Well sorted fine sand - Gray - No Fluorescence
40	1404	49	0-5	2	160	Well sorted fine sand - Gray
41	1285	50	0	4	196	Silt with fine sand - Gray - Brown
42	1048	37	10-20	8	194	Well sorted fine sand - Gray
43	764	28	10-20	5	156	Well sorted fine sand - Gray - No Fluorescence
44	698	25	10-20	4	144	Well sorted fine sand - Gray
45	1219	49	0-10	2	155	Well sorted fine sand - Gray
46	998	40	0-5	4	169	Well sorted fine sand - Gray
47	1215	44	0	2	145	Silt with fine sand - Gray
48	1100	39	0	2	128	Silt with fine sand - Gray - Brown
49	1088	36	0-10	1	116	Well sorted fine sand - Gray
50	1156	41	0-10	2	146	Well sorted fine sand - Gray
51	961	38	0	3	139	Silt with fine sand - Gray - Brown
52	1061	40	0	2	149	Silt with fine sand - Gray - Brown

Core ID	weight (g)	length (cm)	ppm	cm	(g)	comment
53	1103	38.5	0-10	6	200.6	Well sorted fine sand - Gray
54	903	39	0	3	138	Silt w fine sand gray to brown (with woody material)
55	980	46	0	3	157	Well-sorted silt -Dark brown
56	1082	40	0-10	3	133	Well sorted fine sand - Gray - No Fluorescence
57	1108	40	0	3	142	Silt with fine sand - Gray - Brown
58	842	28	10-30	5	137	Well sorted fine sand - Gray - No Fluorescence
59	919	34	0	2	119	Silt with fine sand - Gray
60	1077	38	0-5	4	147	Well sorted fine sand - Gray
61	1147	40	0-10	3	148	Well sorted fine sand - Gray
62	1094	40	0-2	2	139	Well sorted fine sand - Gray
63	1109	39	1-10	3	151	Well sorted fine sand - Gray
64	1081	37	1-10	3	144	Well sorted fine sand - Gray
65	959	38	0-3	3	142	Silt with fine sand - Gray
66	901	39	0	4	149	Silt with fine sand - Gray - Brown
67	1176	40	0-2	5	167	Silt with fine sand - Gray - Brown
68	751	30	0-10	5	142	Silt with fine sand - Gray
69	1145	39	0-13	2	147	Silt with fine sand - Gray
70	1019	39	0-1	2	135	Silt - Brown
71	1020	40	0-1	4	156.5	Silt with fine sand - Brown
72	1140	39	1-11	3	148	Silt with fine sand - Gray
73	1022	40	0-1	5	171	Silt - Brown (with woody debris)
74	1062	39	0-1	3	138	Silt with fine sand - Brown
75	1106	38	0-1	3	133	Silt with fine sand - Gray
76	1107	39	0-2	2	132	Silt with fine sand - Gray - Brown
77	703	28	0	4	126.4	Silt with fine - Light to dark brown (with woody debris)
78	1081	39	0	4	154	Silt with fine sand - Gray - Brown
79	1184	43	1-10	4	160.8	Fine Sand w Silt - Gray
80	1068.5	39	0	3	168	Silt with fine sand - Brown
81	1158	39	0-10	3	153	Well sorted fine sand - Gray
82	922	38	0	2	143	Silt with fine sand - Brown



Core ID	weight (g)	length (cm)	ppm	cm	(g)	comment
83	1371	52	0	4	181	Silt with fine sand - Brown
84	183	40	0	2	140.7	Silt with fine sand - Brown - Gray
85	1057	39	0-6	3	149	Fine Sand w Silt - Gray
86	1066	40	0	3	143	Fine Sand w Silt - Gray (Interbeds of light gray)
87	938	39	0	3	150.1	Silt with fine sand - Brown - Gray
88	446	18	0-10	8	156	Well sorted fine sand - Gray
89	566	21	0-15	6	164	Well sorted fine sand - Gray
90	1058	38	0-1	3	142	Fine Sand w Silt - Gray to Brown
91	771	29	0	4	133	Silt with fine sand - Brown
92	951	38	0	4	149	Silt well sorted - Brown - (with woody debris)
93	881	33	0	3	138	Silt with fine sand - Brown
94	970	39	0	4	157	Silt well sorted - Brown - (with woody debris)
95	901	31	0-5	4	144	Well sorted fine sand - Gray
96	664	25	0-24	6	160.9	Well sorted fine sand - Gray - Minor 1mm by 5mm Fluorescence
97	1130	41	0-16	5	165.7	Well sorted fine sand - Gray
98	936	38	0	4	150.86	Silt well sorted - Brown - (with woody debris)
99	839	37	0	3	143.6	Silt well sorted - Brown - (with woody debris)
100	143	39	0	4	149.5	Silt well sorted - Brown
101	689.5	26	0-1	4	128.4	Silt with fine sand - Gray - Brown
102	1054	38	0-2	3	139.5	Silt with fine sand - Gray - Brown
103	976.2	38	0-2	4	153.4	Silt well sorted - Brown
104	1054	39	0	5	156.1	Silt with fine sand - Gray - Brown
105	972	38	0	2.5	137.8	Silt well sorted - Dark to Light Brown
106	774	26	0-20	5	131.6	Silt with fine sand - Gray
107	949.2	35	0-1	5	141	Silt with fine sand - Gray to Brown
108	914.2	40	0	4	154.4	Silt well sorted - Brown
109	1125.6	38	0-11	3	139.5	Well sorted fine sand - Gray
110	1151.6	39	0-15	2.5	138.5	Well sorted fine sand - Gray
111	698.1	25	0-18	6	153.3	Well sorted fine sand - Gray
112	911	41	0	3	147.1	Silt well sorted - Brown

Core ID	weight (g)	length (cm)	ppm	cm	(g)	comment
113	1030.2	40	0	4	161.5	Silt with fine sand - Brown
114	1047.8	38	0	3	139.8	Silt with fine sand - Brown
115	1012.6	39	0	5	159.6	Silt with fine sand - Brown
116	943.9	39	0	4	151.1	Silt well sorted - Brown (with woody debris)
117	1104.4	40	0-1	3	143.8	Silt with fine sand - Gray to Brown
118	1160.03	40	0-21	2	147	Well sorted fine sand - Gray
119	812	30	0-4	1.5	114	Silt with fine sand - Gray to Brown
120	1000	41	0	3	143.8	Silt well sorted - Brown (with woody debris)
121	1086.1	38	0-20	3	155.8	Well sorted fine sand - Gray
122	984.1	39	0	3	149.1	Silt well sorted - Brown (with woody debris)
123	1091.4	40	0-6	3	152.5	Fine Sand w Silt - Gray to Brown
124	1014.5	38	0-2	4	179.1	Silt with fine sand - Brown
125	503.7	21	0-7	7	131.7	Well sorted fine sand - Gray
126	693.4	30	0	3	127.9	Silt well sorted - Brown - (with woody debris)
127	1108.2	38	0-22	4	158	Fine sand well sorted - gray
128	1078.1	40	0	3	140.8	Silt with fine sand - Brown
129	869.4	41	0	4	145.5	well sorted silt dark brown - (with woody debris)
130	993	38	0	5	147.6	well sorted silt dark brown - (with woody debris)
131	1015.3	38	0-8	8	201.8	Fine sand well sorted - gray
132	1112.9	39	0-1	3	139.4	Silt with fine sand - Brown to gray
133	752.6	40	0	2.5	142.2	well sorted silt brown - (with woody debris)
134	844.6	32	0	7	152.3	Silt with fine sand - Brown and gray
135	1082.2	38	0-25	6	166	Fine sand well sorted - gray
136	907.2	36	0-2	3	140.8	Silt with fine sand - Brown
137	890.2	39	0	3.5	147.1	well sorted silt dark brown - (with woody debris)
138	1054.8	37	0-8	5	168.1	Fine sand well sorted - gray
139	960.5	39	0	3.5	151.1	well sorted silt brown - (with woody debris)
140	1087.3	40	0-2	4	169.2	Silt with fine sand - gray
141	968.1	39	0	6	159.2	Silt with fine sand - Brown
142	888.9	38	0	4	162.7	Silt with fine sand - dark Brown

Core ID	weight (g)	length (cm)	ppm	cm	(g)	comment
143	1089.7	38	0-3	3	148.9	Fine sand well sorted - gray
144	1148.8	40	0-32	3	161.2	Fine sand well sorted - gray
145	1053.3	39	0-3	2	138.8	Silt with fine sand - Brown to gray
146	1060.1	40	0	3	140.6	Silt with fine sand - Brown
147	1102.4	39	0-11	3.5	141.1	Fine Sand w Silt - Gray to Brown
148	889.5	31.5	0-36	5	150.1	Fine sand well sorted - gray



## APPENDIX B - ANALYTICAL METHODS & QA/QC

### *Analytical Methods*

Sample preparation consisted of extraction of target compounds into MTBE (VWR) using an extraction protocol adapted from USEPA Method 551.1 (Methods for Determination of Organic Compounds in Drinking Water Supplement II).

Analysis for chlorinated compounds was conducted using GC/ECD (Hewlett Packard 5890 Series II, Agilent DB-624 column).

Chloride analysis was conducted using an ion selective electrode (Cole Parmer Instruments).

Calibration of all analytical equipment was conducted prior to and following all sample sets. Calibration checks were analyzed at a rate of 10%.

Iron content in treated samples was determined by:

- 1) Adding ~ 20mL deionized water/ gram treated soil.
- 2) Mixing the solution until all soil particles were dispersed.
- 3) Passing a high power magnet wrapped in cellophane through the slurry repeatedly until all of the magnetic iron was collected.
- 4) Removing the cellophane and iron from the magnet.
- 5) Drying the wet iron – soil at 100C
- 6) Dry the remaining wet soil
- 7) Grind the dry iron with a mortar and pedestal to remove soil adhering to the iron.
- 8) Using a high power magnet wrapped in cellophane to remove magnetic iron from the dried sediment.
- 9) Removing the cellophane and iron from the magnet.
- 10) Measuring the weight of extracted iron.
- 11) Calculate the fraction iron as the mass of extracted iron divided by the dry weight of the soil.

### *Quality Assurance/Quality Control*

To assess the quality of the data collected as part of the ZVI-Clay efficacy study, several analyses were conducted:

Replicate analyses  
Outside lab analysis

## Laboratory Control Samples

A total of 9 sets of replicates (seven sets of duplicates and 2 sets of triplicates) were analyzed over the course of the study. This amounted to approximately 15% of the total samples analyzed. For PCE the relative percent difference (RPD) ranged from 101% to 5%, with a mean RPD of 29%. The high RPD is the result of one set of duplicates in which the RPD is 101% (spiked 3% Peerless). The analyses of triplicates indicated relative standard deviations (RSD) of 15% and 7.5% with a mean RSD of 11.25%. For TCE, analysis of duplicates indicated a range in RPD from 108% to 1%, with a mean RPD of approximately 35%. The high RPD is primarily due to the single value of 108% (unspiked control). For TCE only one of the triplicate sets resulted in values above detection with a RSD of 14%. For c-DCE, calculation of the RPD and RSD was not possible due to the high number of non-detects.

Four samples were submitted to Energy Laboratories, Inc. (Billings MT). Results indicated a mean RPD of 19% and 25% for PCE and TCE, respectively. RPD for c-DCE between the CSU and Energy Laboratory analyses cannot be calculated because of non-detect values.

The replicate analysis and the outside lab analysis provide information regarding the overall repeatability of the experiment. Given the large number of sources variability that are included in the RPD and RSD given above (e.g. contaminant distribution between reaction vials, variability in iron distribution between reaction vials, variability in volatile losses between reaction vials, variation in extraction efficiency between reaction vials, analytical variability), the RSD and RPD determined for this study are within expected values.

Laboratory Control Samples (LCS) were run to maintain control over the operation of the GC-ECD. LCS were run following every 10 analyses at a minimum. None of the LCS indicated a greater than 10% RPD during the analysis of the samples associated with this study.

# Appendix C

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## Removal Action Summary Report



## **Williams Environmental Services, Inc.**

*A Compass Environmental, Inc. Company*



March 29<sup>th</sup>, 2005

Mr. Chris Bozzini  
CH2M Hill, Inc.  
4824 Parkway Plaza Blvd., Suite 200  
Charlotte, NC 28217

Subject: In-situ SSM  
Source Removal Through Soil Mixing  
Camp Lejeune, North Carolina  
Transmittal No. 010

RE: Summary Report  
Williams' Project No. 0600-0200

Dear Chris;

Please find the Summary Report for the subject project, for your review. Enclosed you will find an original and two copies of the referenced report, as requested.

Should you have any questions or need any further information, please contact our Texas office at (972) 335-3282.

Sincerely,

**Williams Environmental Services, Inc.**

Jeffrey H. Sallas  
Project Manager

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- 2.0 Remedial Methods and Events
  - 2.1 Mobilization and Site Preparation
  - 2.2 Soil Mixing Activities
    - 2.2.1 SSM Treatment
    - 2.2.2 Iron-Bentonite Slurry Mixture Sampling and Testing
    - 2.2.3 VOC(s) Extraction
- 3.0 Health and Safety Program
  - 3.1 Training and Health Monitoring Requirements
  - 3.2 Air Monitoring Program
  - 3.3 General Site Conditions and Hazards
  - 3.4 Emergency Response/Contingency Plan
- 4.0 Summary and Conclusion
  - Attachments
    - Attachment No. 1
      - Magnetic Separation Sampling Test Results
    - Attachment No. 2
      - Column As Built Drawings
  - Appendix A
    - Daily Construction Quality Assurance Reports
  - Appendix B
    - Daily Quality Control Drilling Reports
  - Appendix C
    - Daily Health and Safety Reports

## **1.0 Site Description**

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The Source Removal Through Soil Mixing with Zero Valent Iron/Clay addition Summary Report for Site 88 located at Camp Lejeune, North Carolina presents a detailed narrative of soil mixing activities recently completed. The soil mixing activities were completed in accordance with the In-Situ SSM Quality Assurance Plan submitted to CH2M Hill, Inc. on November 9, 2004.

Site 88 is located approximately 500 feet east of the intersection of Post Land Road and Main Service Road at the Camp Lejeune Marine Corps Base in North Carolina. Site 88 is part of an Operable Unit number 15 and consists of Building 25 and the surrounding paved grassy areas. Building 25 operated as the Base Dry Cleaning facility from the 1940's until 2004, when it was demolished to slab.





## **2.0 Remedial Methods and Events**

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The remedial activities performed at the Site included soil mixing with zero valent iron/clay addition.

### **2.1 Mobilization and Site Preparation**

Williams mobilized to the site on January 17, 2005, to initiate site preparation activities. Site preparation activities were completed by February 10, 2005 and included:

- Mobilization of equipment and materials
- Assembly of Manitowoc 4100 series crane
- Assembly of Batch Plant
- Establishing parking areas, haul routes, and work zones for authorized personnel
- Laying out outline of soil mixing area
- Installing fencing to establish EZ zone

### **2.2 Soil Mixing Activities**

Soil mixing activities were conducted from February 11, 2005, until February 28, 2005. The treated soil columns were constructed using a crane mounted Hain 450 Turn Table. The Drill Rig was equipped with a hollow Kelly Bar that rotated a 10-foot diameter auger that blended the soil to a uniform consistency. A batch plant was constructed on site to prepare the iron-bentonite slurry mixture to the project specifications. Soil mixing activities were recorded each day in Williams' Daily Construction Quality Assurance reports and are located in Appendix A of this report.

#### **2.2.1 SSM Treatment**

Engineering design drawings were provided by the client that delineated the area of impact. The centers of the columns were positioned in the impacted area so the columns overlapped to remediate 100 percent of the impacted soils. The center points of each column were laid out each day prior to drilling by Williams' Quality Control Officer using a total station. Upon establishing each center point, the Mixing Rig was positioned over



the established point for drilling. During soil mixing activities, 146 columns were advanced and 7051.26 cubic yards of impacted soil was treated. Each column was advanced to a depth of 20 feet below the ground surface. The area of impacted was excavated approximately 3.5 feet below original ground surface prior to drilling. Daily summaries of columns advanced and cumulative total volume of material treated are presented in the Daily Quality Control Drilling Reports located in Appendix B of this report. Figure 1 illustrates the columns advanced each day.

The prescribed grout mixture was injected through the augers as the augers rotated and mixed with the impacted soil. The grout mixture consisted of four batches. Batches one, two, and three, consisted of 3, 100-pound bags of Bentonite and 400 gallons of water each. Batch four consisted of 2, 100-pound bags of Bentonite and one bag of either 2,500 lbs or 2,230 lbs of iron filings, depending on the column location. Figure 2 illustrates the ZVI distribution for the columns. Upon injection completion of the iron filings, each column was mixed at a minimum of six times.

### ***2.2.2 Iron-Bentonite Slurry Mixture Sampling and Testing***

Samples were collected each day at depths of 5 feet and 15 feet. Williams' wet sampling tool was lifted with a hydraulic excavator and inserted into freshly mixed columns to the desired depth. Approximately 100 grams of the composite sample was used in the magnetic separation testing. First, the dry unit weight was determined for each sample. Each sample was then washed several times to remove fine materials. A magnet was used to separate the iron from the mixture while the mixture was wet. The separated iron was then dried and a magnet was used again to separate iron filings from the remaining sand in the mixture. Table 1 presents a summary of iron contents for each column sampled. Sample results were also recorded on each day's Daily Construction Quality Assurance Report located in Appendix B of this report.

### ***2.2.3 VOC(s) Extraction***

Williams installed a soil vapor extraction system onsite to capture volatilized contaminants that escaped through the annulus created by the rotating Kelly bar during drilling operations. The system consisted of a 14-foot diameter shroud that covered the area of the mixing column. Additional components of the system included a HEPA filter for dust

particle removal, a 3000-pound granular Activated Carbon container and a discharge stack. Williams monitored off-gas during drilling activities using a hand-held PID to ensure that carbon breakthrough did not occur. Monitoring was performed each day of drilling every two hours at the intake of the carbon container and at the discharge stack. No readings were recorded over 0ppm from the discharge stack. Daily peak results and averages are recorded on the Daily Health and Safety logs located in Appendix C of this report.





### **3.0 Health and Safety Program**

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All work was conducted in compliance with the industry standards for work at hazardous waste sites presented in 29 CFR 1910.120 and industry standards for the construction industry presented in 29 CFR 1926. A site-specific Health and Safety plan (HASP) was developed by Williams for soil mixing activities. The HASP applied to all employees and visitors at the Site. Common elements of the HASP are briefly described below.

#### **3.1 Training and Health Monitoring Requirements**

Copies of current OSHA 40-Hour Hazardous Waste Operations training and eight hour refresher course certificates were required of all personnel prior to working on Site. Proof of participation in an annual medical surveillance program and documentation of a successful respirator fit test within the past 12 months for the appropriate type of respirator needed for onsite work were also required for each employee.

#### **3.2 Air Monitoring Program**

The air quality in work areas was routinely monitored on a real-time basis for VOCs using a PID during soil mixing activities. Air monitoring results were used to determine the level and type of personal protective equipment (PPE) required for personnel working in specific areas. Measurements were recorded each day in the areas immediately surrounding the vapor shroud, the carbon container intake, the carbon discharge stack, and area near the entrance to the site. No results were recorded over 0 ppm, with the exception of the carbon intake. Result peaks and averages are recorded on the Daily Health and Safety logs located in Appendix C of this report.

#### **3.3 General Site Conditions and Hazards**

All personnel assigned to the site were advised of the hazards associated with soil mixing activities. Hazard information was made available in the HASP and included material safety data sheets, chemical/physical hazards, PPE, and hazardous materials labeling. In addition, the HASP presented an overview of hazards associated with excavation and trenching, heavy equipment operation and operator awareness, truck traffic, electrical power, lockout/tagout requirements, and eye and hearing protection. Each person working at the Site signed an acknowledgement form indicating



that he had been informed and understood the procedures and protocols established in the HASP. Tailgate health and safety meetings were held daily to review and present applicable safety protocols as well as to inform all personnel of changing Site conditions and address workers concerns. Additionally, all workers completed a Task Safety evaluation each day to outline safety issues concerning his specific task to be completed.

### **3.4 Emergency Response/Contingency Plan**

A map with routes to the nearest hospital, emergency contact, and telephone numbers were posted in the on-site trailer near the telephone. A list of emergency equipment available onsite and the Site-specific HASP were placed in a central location in the on-site trailer. A field first aid kit, eyewash station, and fire extinguishers were located on Site during all activities.



#### **4.0 Summary and Conclusion**

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In summary, the Site 88 Source Removal project was successfully completed in compliance with the requirements of the implementation plan. Some notable accomplishments during the project were:

- Approximately 7052 cubic yards of source material was successfully treated through soil mixing with zero valent iron/clay addition;
- Air monitoring results revealed the soil vapor extraction shroud successfully controlled off-gas at the Site;
- Magnetic separation sampling confirmed zero valent iron addition requirements were met and exceeded in some areas.





## Attachments

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Summary Report  
Site 88 Source Removal through Soil Mixing  
Camp Lejeune, North Carolina



**Attachment No. 1**  
**Magnetic Separation Sampling Test Results**

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Summary Report  
Site 88 Source Removal through Soil Mixing  
Camp Lejeune, North Carolina



**Table 1**  
**Summary of Magnetic Separation Sampling Results**  
**Source removal Through Soil Mixing, Site 88**  
**Camp Lejeune, North Carolina**

Sample ID	Date	Depth	Weight Iron/soil/bentonite + tare (DRY)	Weight Iron/soil/bentonite + tare (WET)	Dry Weight of Iron/soil/bentonite	Weight of Iron + tare	Weight of tare	Weight of Iron	% ZVI
29	2/14/05	5	645	616	29	3.8	3.1	0.7	2.4
		15	662	631	31	3.4	2.6	0.8	2.6
5	2/15/05	5	703	662	41	4.8	3.1	1.7	4.1
		15	666	633	33	4.1	2.8	1.3	3.9
13	2/15/05	5	662	634	28	3.7	2.5	1.2	4.3
		15	662	637	25	3.5	2.6	0.9	3.6
36	2/15/05	5	668	640	28	4.1	3	1.1	3.9
		15	670	636	34	3.2	2.5	0.7	2.1
51	2/16/05	5	700	657	43	4.3	2.7	1.6	3.7
		15	693	659	34	3.9	2.5	1.4	4.1
64	2/18/05	5	626	607	19	4.5	3.7	0.8	4.2
		15	690	657	33	4.8	3.4	1.4	4.2
114	2/19/05	5	651	625	26	3.8	2.4	1.4	5.4
		15	682	653	29	3.55	2.3	1.25	4.3
115	2/21/05	5	674	645	29	4.6	3.2	1.4	4.8
		15	693	655	38	5.1	2.9	2.2	5.8
106	2/22/05	5	712	672	40	4.8	2.6	2.2	5.5
		15	702	656	46	5.3	2.9	2.4	5.2
123	2/23/05	5	675	642	33	3.9	2.2	1.7	5.2
		15	708	672	36	3.7	2	1.7	4.7
125	2/24/05	5	703	660	43	4.4	2.3	2.1	4.9
		15	713	666	47	4.4	2.1	2.3	4.9
143	2/25/05	5	684	647	37	4.3	2.2	2.1	5.7
		15	698	655	43	4.5	2.2	2.3	5.3
146	2/26/05	5	684	651	43	4.6	2.4	2.2	5.1
		15	716	674	42	3.8	1.9	1.9	4.5
16	2/28/05	5	709	664	45	3.2	1.7	1.5	3.3
		15	705	659	46	3.3	1.7	1.6	3.5



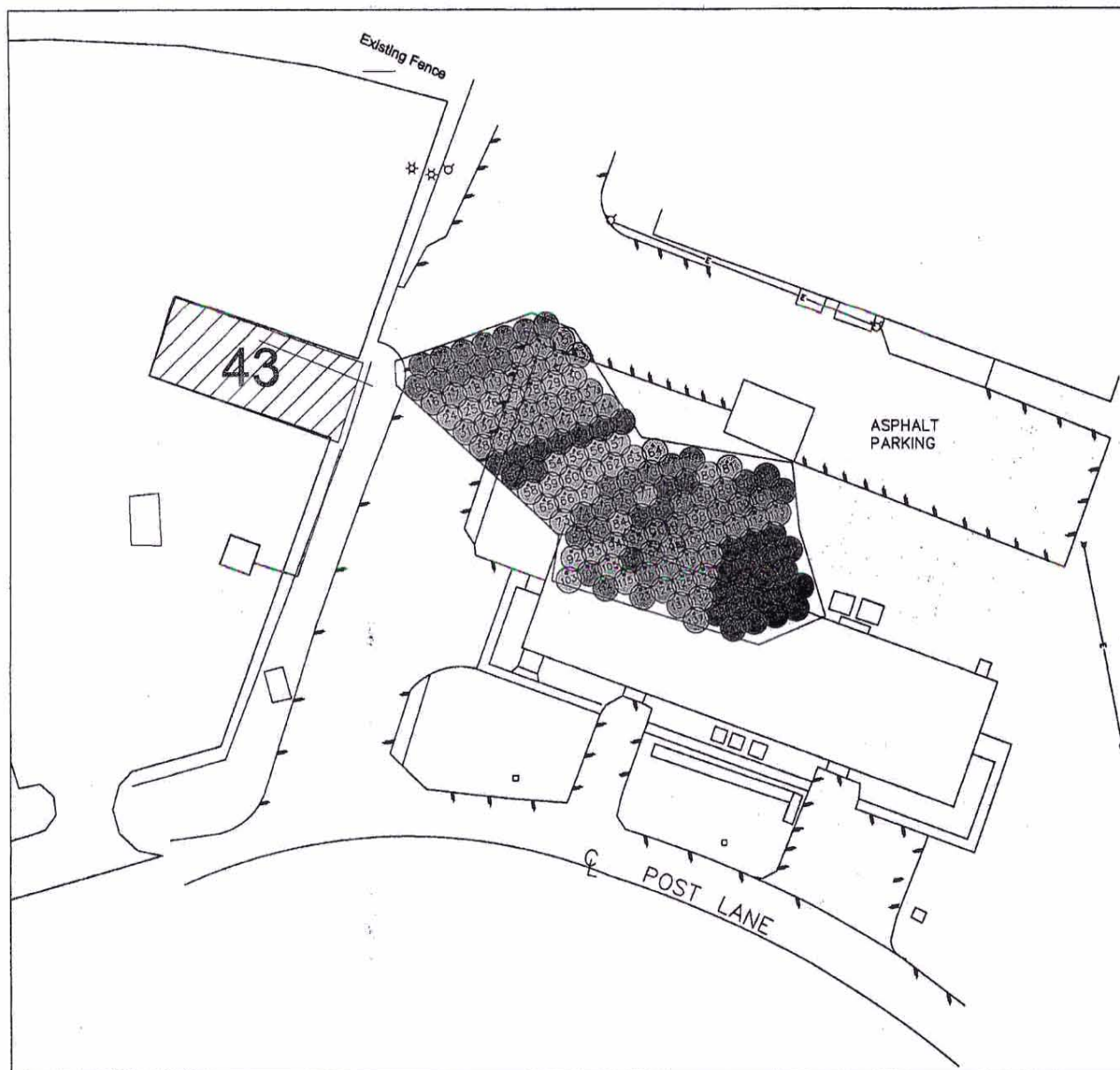
**Attachment No. 2**  
**Column As Built Drawings**

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Summary Report  
Site 88 Source Removal through Soil Mixing  
Camp Lejeune, North Carolina



**COMPASS**  
ENVIRONMENTAL, INC.



# DATES

- 2-11 ●
- 2-12 ●
- 2-14 ●
- 2-15 ●
- 2-16 ●
- 2-18 ●
- 2-19 ●
- 2-21 ●
- 2-22 ●
- 2-23 ●
- 2-24 ●
- 2-25 ●
- 2-26 ●
- 2-28 ●

- 2500 LBS  
INJECTED ZVI
- ▲ 2230 LBS  
INJECTED ZVI

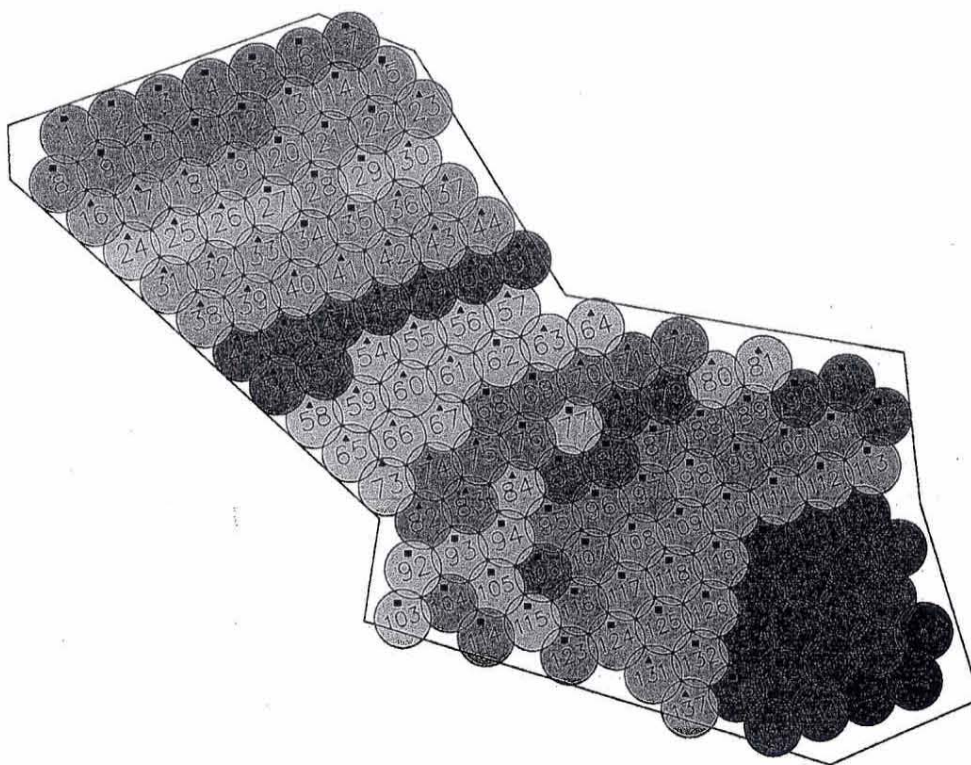
## Column Data

US Navy

North Carolina

SCALE		5	0	10	PROJECT NUMBER	FIGURE NUMBER
					060-0200	1
		1" = 10'				
DRAWN BY	2JB	CHECKED BY	JB	APPROVED BY	JB	DATE
						3-9-2005





# DATES

2-11	●
2-12	●
2-14	●
2-15	●
2-16	●
2-18	●
2-19	●
2-21	●
2-22	●
2-23	●
2-24	●
2-25	●
2-26	●
2-28	●

- 2500 LBS  
INJECTED ZVI
- ▲ 2230 LBS  
INJECTED ZVI

Column Data			
US Navy			
North Carolina			
SCALE	5 0 10	PROJECT NUMBER	FIGURE NUMBER
	1" = 10'	000-0200	1
DRAWN BY	CHECKED BY	APP'D BY	DATE
ELH	JB	JB	3-9-2006



# Appendix D

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## Test Area Solidification Results



April 27, 2005

Project No. 2005-522-01

Ms. Louise Palmer  
CH2M Hill, Inc.  
4824 Pkwy Plaza Blvd., Suite 200  
Charlotte, NC 28217

**Transmittal**  
**Laboratory Test Results**  
**Camp Lejeune – Site 88**

Please find attached the laboratory test results for the above referenced project. The tests were outlined on the Project Verification Form that was faxed to your firm prior to the testing. The testing was performed in general accordance with the methods listed on the enclosed data sheets. The test results are believed to be representative of the samples that were submitted for testing and are indicative only of the specimens which were evaluated. We have no direct knowledge of the origin of the samples and imply no position with regard to the nature of the test results, i.e. pass/fail and no claims as to the suitability of the material for its intended use.

The test data and all associated project information provided shall be held in strict confidence and disclosed to other parties only with authorization by our Client. The test data submitted herein is considered integral with this report and is not to be reproduced except in whole and only with the authorization of the Client and Geotechnics. The remaining sample materials for this project will be retained for a minimum of 90 days as directed by the Geotechnics' Quality Program.

We are pleased to provide these testing services. Should you have any questions or if we may be of further assistance, please contact our office.

Respectfully submitted,  
**Geotechnics, Inc.**

Michael P. Smith  
Regional Manager

***We understand that you have a choice in your laboratory services  
and we thank you for choosing Geotechnics.***

DCN: Data Transmittal Letter Date: 1/28/05 Rev.: 1

2200 Westinghouse Boulevard • Suite 105 • Raleigh, NC 27604 • Phone (919) 876-0405 • Fax (919) 876-0460



## TORVANE SHEAR RESULTS

Client	CH2M HILL	Boring No.	NA
Client Reference	CAMP LEJUENE	Depth (ft)	NA
Project No.	2005-522-01	Sample No.	1
Lab ID	2005-522-01-01	Visual Description	BROWN SANDY CLAY

<u>DEPTH</u>	<u>SHEAR VALUE (25mm VANE)</u>
SURFACE	0.0
-6 INCHES	0.0
-10 INCHES	0.9

NOTE: Torvane tests performed on sample material as received from client in 5 gal. Bucket (typical) at depths noted.

Tested By MPS Date 3/16/2005 Checked By *cam* Date 3-21-05

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page 1 of 1



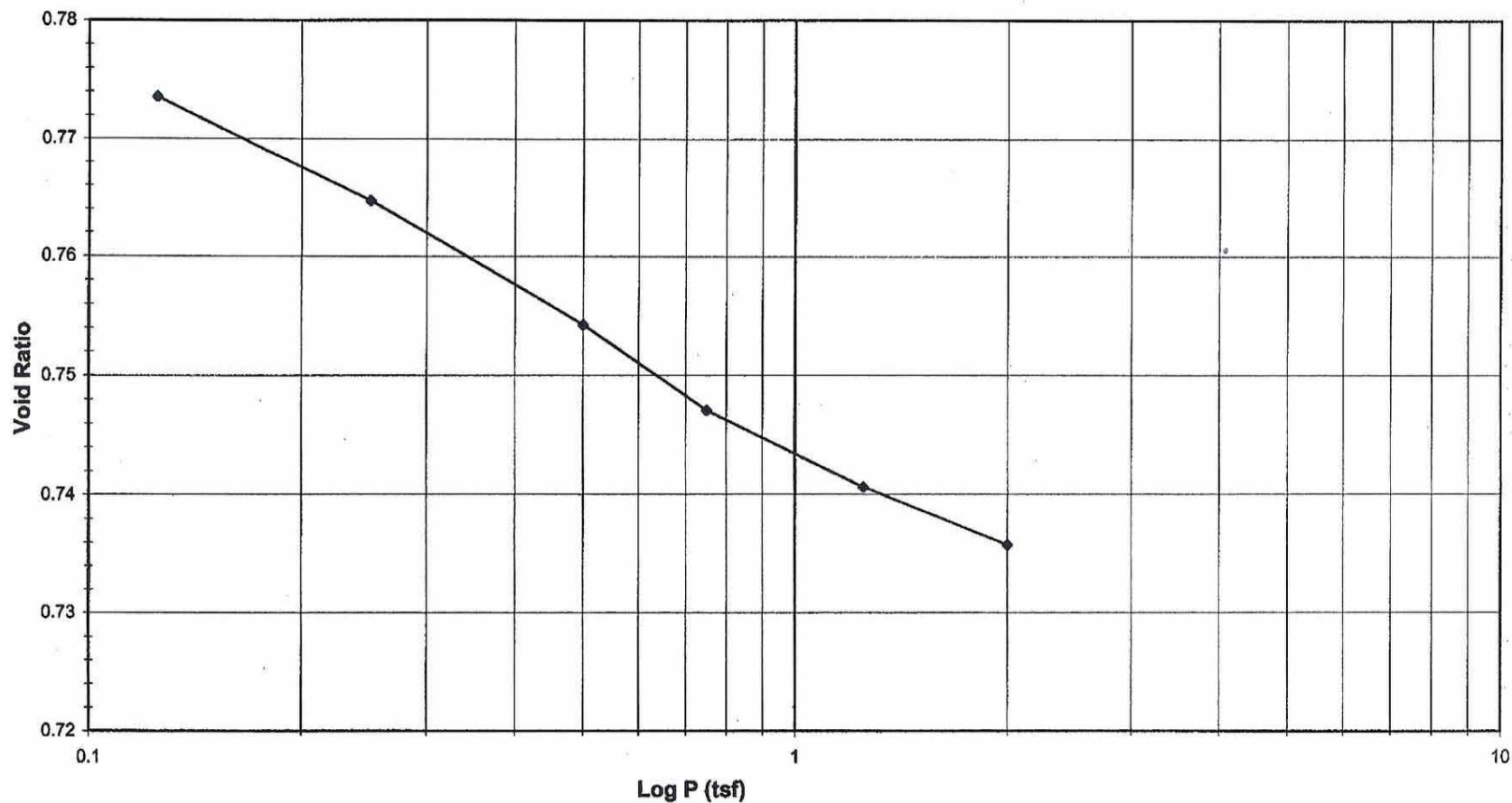
# ONE DIMENSIONAL CONSOLIDATION

ASTM D 2435-96 (SOP-S24)

Client CH2M HILL  
Client Reference CAMP LEJEUNE - SITE 88  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft) NA  
Sample No. 1  
Visual Description BROWN SANDY CLAY

**Sample Conditions:** REMOLDED, INUNDATED AND DOUBLE DRAINED



Tested By MPS Date 3/16/2005 Approved By *[Signature]* Date 4-4-05



## ONE DIMENSIONAL CONSOLIDATION

ASTM D 2435-96 (SOP-S24)

Client CH2M HILL  
Client Reference CAMP LEJEUNE - SITE 88  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft) NA  
Sample No. 1  
Visual Description BROWN SANDY CLAY

**Sample Conditions:** REMOLDED, INUNDATED AND DOUBLE DRAINED

**Consolidometer No.** 275  
**1 Division** = 0.0001 (in)

<u>Sample Properties</u>	<u>Initial</u>	<u>Final</u>
<i>Water Content</i>		
Tare Number	A-3	F-1
Wt. Tare & WS (gm)	237.14	245.43
Wt. Tare & DS (gm)	207.99	218.25
Wt. Water (gm)	29.15	27.18
Wt. Tare (gm)	98.58	98.46
Wt. DS (gm)	109.41	119.79
Water Content (%)	26.64	22.69
<i>Sample Parameters</i>		
Sample Diameter (in)	2.5	2.5
Sample Height (in)	1.000	0.964
Sample Volume (cc)	80.44	77.52
Wt. Wet Sample + Ring (gm)	2015.40	2010.63
Wt. of Ring (gm)	1862.70	1862.70
Wt. of Wet Sample (gm)	152.70	147.93
Wet Density (pcf)	118.45	119.09
Wet Density (g/cc)	1.90	1.91
Water Content (%)	26.64	22.69
Wt. of Dry Sample (gm)	120.58	120.58
Dry Density (pcf)	93.53	97.06
Dry Density (g/cc)	1.50	1.56
Void Ratio	0.8013	0.7358
Saturation (%)	89.78	83.26
Specific Gravity	2.70	Assumed

<u>Test Data Summary</u>							
<u>Applied Pressure</u>	<u>Final Dial Reading</u>	<u>Machine Deflection</u>	<u>Corrected Reading</u>	<u>Height of Sample</u>	<u>Volume (cc)</u>	<u>Dry Density</u>	<u>Void Ratio</u>
(tsf)	(div)	(div)	(div)	(mm)		(g/cc)	
Seating	0	0	0	25.400	80.440	1.49895	0.80126
0.125	158.3	4.5	153.8	25.009	79.203	1.52236	0.77356
0.25	214.1	11.1	203.0	24.884	78.807	1.53001	0.76470
0.5	284.3	23.4	260.9	24.737	78.341	1.53911	0.75427
0.75	331.7	31.0	300.7	24.636	78.021	1.54542	0.74710
1.25	378.5	42.0	336.5	24.545	77.733	1.55115	0.74065
2	419.3	55.8	363.5	24.477	77.516	1.55549	0.73579

Tested By MPS Date 3/16/2005 Input Checked By JLAW Date 4-13-05

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 0%A  
Visual BROWN SANDY CLAY

INITIAL SAMPLE DIMENSIONS			
Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in.^2)	3.142

WATER CONTENT	
Tare No.	B-2
Wt. Tare + WS.(gms)	41.03
Wt. Tare + DS.(gms)	36.77
Wt. of Tare(gms)	22.06
% Moisture	28.96

UNIT WEIGHT			
Wt. Tube & WS.(gms.)	380.6	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.85
Wt. Of WS.(gms.)	380.64	Unit Wet Wt.(pcf.)	115.34
Diameter (in.)	2.00	Moisture Content, %	28.96
Length (in.)	4.00	Unit Dry Wt.(pcf.)	89.44
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
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UNABLE TO RUN TEST, THE SAMPLE COLLAPSED UNDER IT'S OWN WEIGHT



**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 0%B  
Visual BROWN SANDY CLAY

**INITIAL SAMPLE DIMENSIONS**

Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in. <sup>2</sup> )	3.142

**WATER CONTENT**

Tare No.	L-1
Wt. Tare + WS.(gms)	43.03
Wt. Tare + DS.(gms)	38.04
Wt. of Tare(gms)	21.99
% Moisture	31.09

**UNIT WEIGHT**

Wt. Tube & WS.(gms.)	381.4	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.85
Wt. Of WS.(gms.)	381.4	Unit Wet Wt.(pcf.)	115.57
Diameter (in.)	2.00	Moisture Content, %	31.09
Length (in.)	4.00	Unit Dry Wt.(pcf.)	88.16
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	0.0	0.00	0.00	0.00
0.002	0.8	0.05	0.05	0.24
0.004	0.7	0.10	0.10	0.22
0.008	1.3	0.20	0.20	0.39
0.014	0.9	0.35	0.35	0.26
0.022	1.2	0.57	0.55	0.39
0.032	1.6	0.82	0.81	0.51
0.048	1.9	1.20	1.19	0.58
0.064	1.6	1.60	1.60	0.50
0.080	2.0	2.02	2.01	0.60
0.096	2.2	2.42	2.40	0.68
0.120	2.2	3.02	3.01	0.67
0.136	2.4	3.42	3.41	0.74
0.169	2.4	4.22	4.21	0.74
0.201	2.5	5.02	5.02	0.75
0.241	3.5	6.03	6.02	1.04
0.261	3.0	6.53	6.52	0.87
0.301	3.5	7.53	7.52	1.03
0.321	3.5	8.03	8.02	1.03
0.361	3.6	9.03	9.03	1.04
0.401	4.0	10.03	10.03	1.13
0.461	4.0	11.53	11.53	1.13
0.522	4.2	13.05	13.04	1.15
0.602	4.8	15.05	15.05	1.29

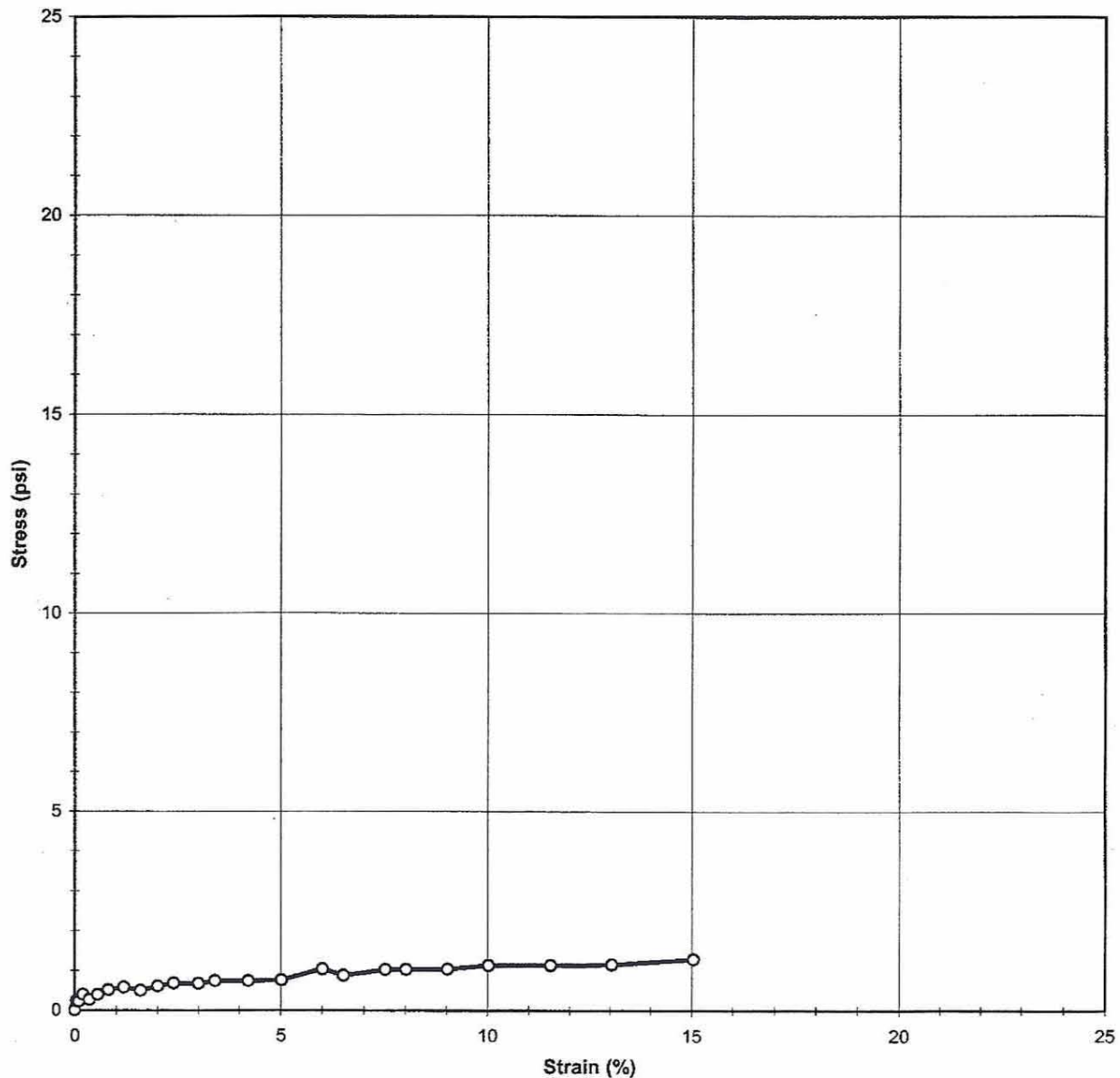
Tested By MPS

Date 4/18/2005 Input Checked By KAW

Date 4-20-05

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client	CH2M HILL	Boring No.	NA
Client Reference	CAMP LEJUENE	Depth (ft.)	NA
Project No.	2005-522-01	Sample No.	0%B
Lab ID	2005-522-01-01	Visual	BROWN SANDY CLAY



Tested By MPS

Date 4/18/2005 Approved By

Date

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 1%A  
Visual BROWN SANDY CLAY

**INITIAL SAMPLE DIMENSIONS**

Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in.^2)	3.142

**WATER CONTENT**

Tare No.	H-2
Wt. Tare + WS.(gms)	42.45
Wt. Tare + DS.(gms)	37.94
Wt. of Tare(gms)	22.03
% Moisture	28.35

**UNIT WEIGHT**

Wt. Tube & WS.(gms.)	383.2	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.86
Wt. Of WS.(gms.)	383.15	Unit Wet Wt.(pcf.)	116.10
Diameter (in.)	2.00	Moisture Content, %	28.35
Length (in.)	4.00	Unit Dry Wt.(pcf.)	90.46
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	1.8	0.00	0.00	0.00
0.002	2.8	0.05	0.05	0.33
0.004	2.9	0.10	0.10	0.37
0.008	3.2	0.20	0.20	0.45
0.014	3.9	0.35	0.34	0.67
0.022	4.5	0.55	0.55	0.85
0.032	4.6	0.80	0.81	0.90
0.048	4.6	1.20	1.19	0.88
0.064	5.1	1.60	1.60	1.05
0.080	4.9	2.00	2.00	0.99
0.096	5.5	2.40	2.40	1.15
0.120	5.8	3.00	3.01	1.25
0.136	5.7	3.40	3.41	1.22
0.168	6.3	4.20	4.20	1.39
0.200	6.6	5.00	5.00	1.45
0.241	6.8	6.02	6.02	1.50
0.261	6.7	6.52	6.52	1.46
0.301	7.5	7.52	7.52	1.68
0.321	7.7	8.02	8.02	1.74
0.361	7.3	9.02	9.02	1.59
0.401	7.4	10.02	10.02	1.61
0.461	7.7	11.52	11.52	1.67
0.521	8.0	13.02	13.03	1.74
0.601	7.7	15.03	15.03	1.62

Tested By MPS

Date 04/18/05 Input Checked By KAW

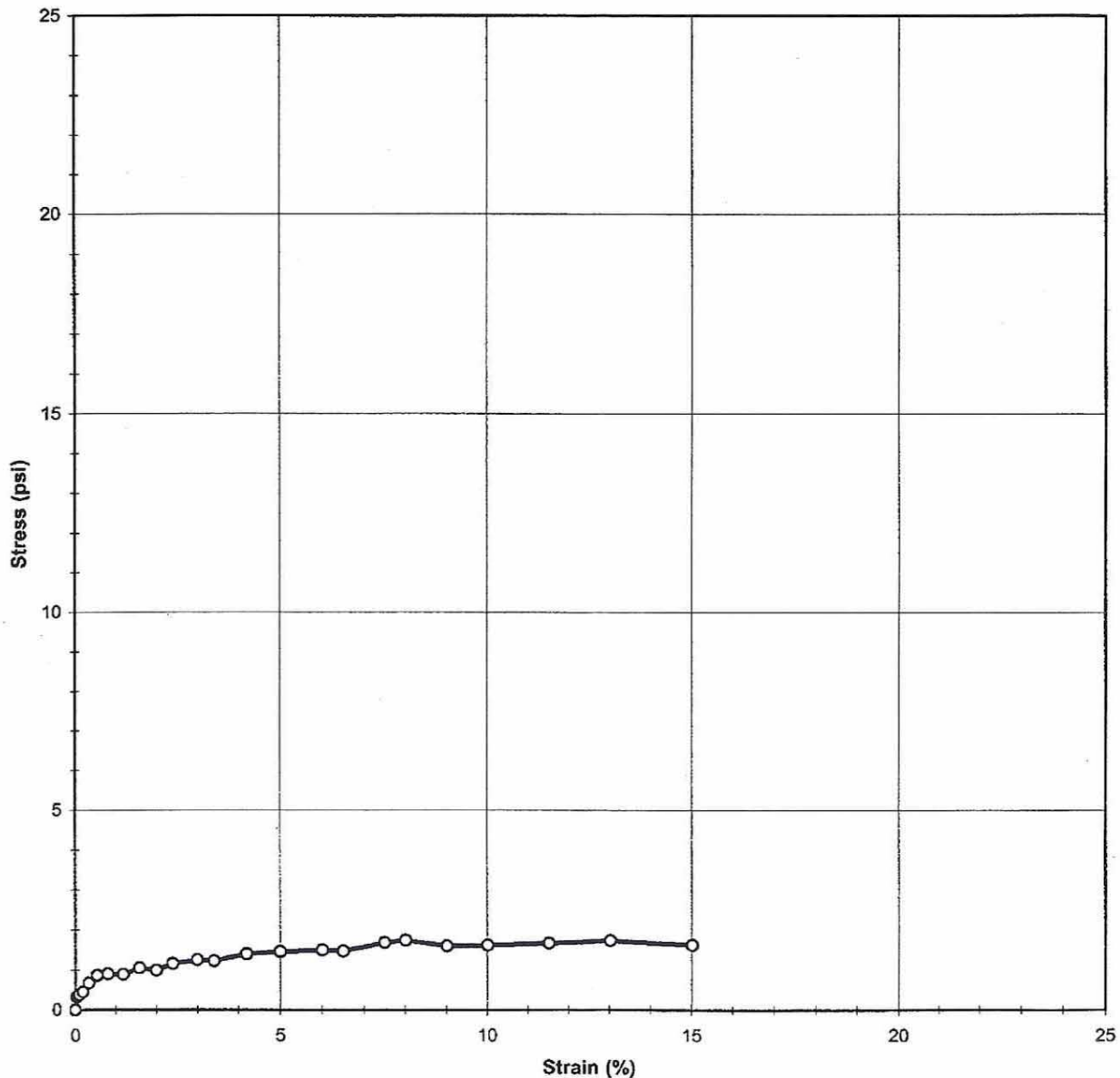
Date 4-20-05



**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 1%A  
Visual BROWN SANDY CLAY



Tested By MPS

Date 04/18/05 Approved By

Date

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 1%B  
Visual BROWN SANDY CLAY

INITIAL SAMPLE DIMENSIONS			
Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in.^2)	3.142

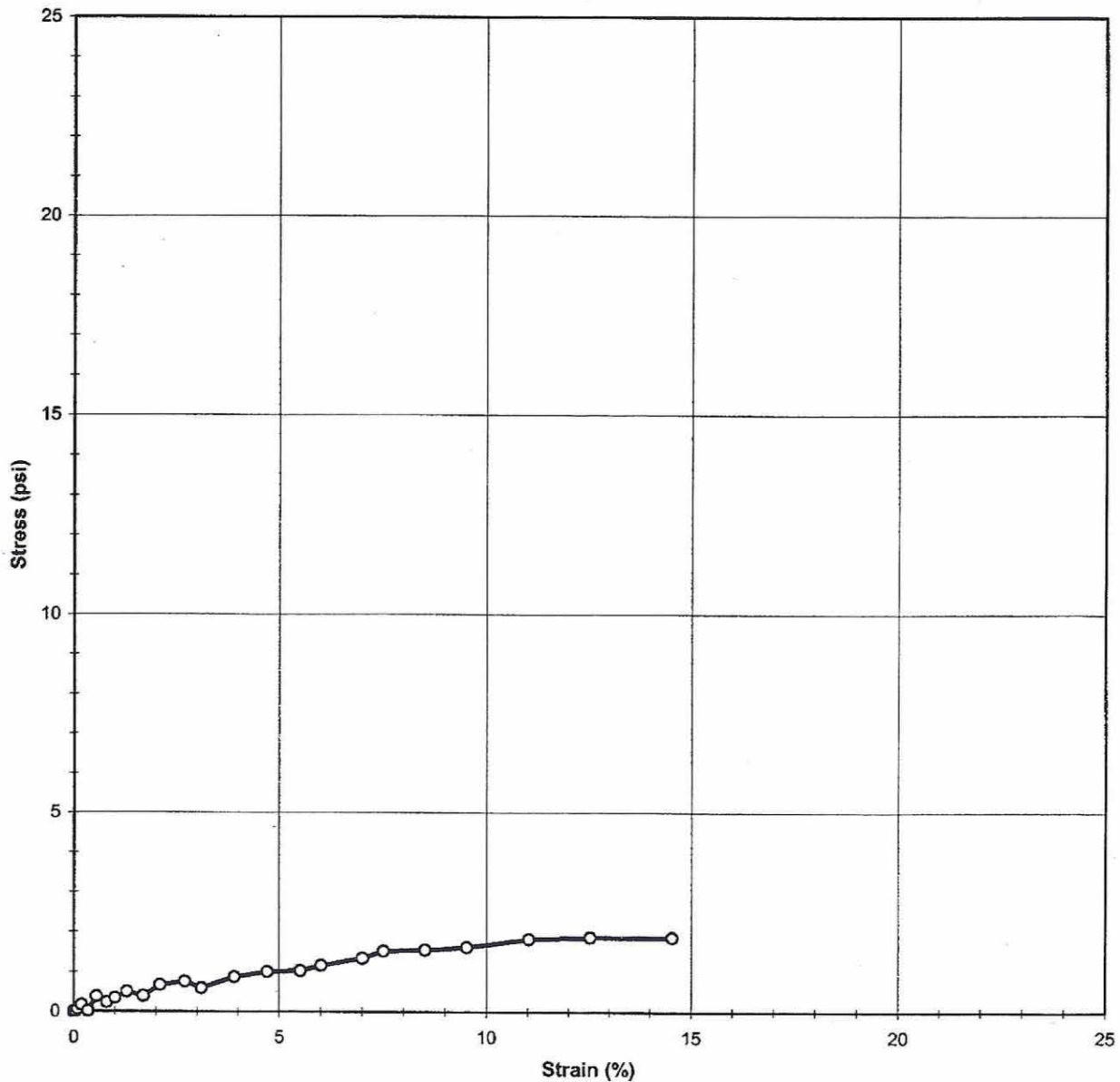
WATER CONTENT	
Tare No.	G-2
Wt. Tare + WS.(gms)	57.34
Wt. Tare + DS.(gms)	49.40
Wt. of Tare(gms)	21.91
% Moisture	28.88

UNIT WEIGHT			
Wt. Tube & WS.(gms.)	382.4	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.86
Wt. Of WS.(gms.)	382.41	Unit Wet Wt.(pcf.)	115.88
Diameter (in.)	2.00	Moisture Content, %	28.88
Length (in.)	4.00	Unit Dry Wt.(pcf.)	89.91
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	1.3	0.00	0.00	0.00
0.002	1.3	0.05	0.04	0.01
0.004	1.4	0.10	0.10	0.06
0.008	1.8	0.20	0.19	0.17
0.014	1.3	0.35	0.35	0.01
0.022	2.4	0.55	0.55	0.38
0.032	2.0	0.80	0.81	0.23
0.040	2.3	1.00	1.01	0.34
0.052	2.8	1.30	1.30	0.49
0.068	2.5	1.70	1.70	0.39
0.084	3.4	2.10	2.10	0.66
0.108	3.7	2.70	2.70	0.75
0.124	3.2	3.10	3.11	0.58
0.156	4.1	3.90	3.90	0.86
0.188	4.5	4.72	4.71	1.00
0.221	4.7	5.52	5.52	1.03
0.241	5.1	6.02	6.01	1.16
0.280	5.8	7.02	7.01	1.34
0.301	6.4	7.52	7.52	1.52
0.341	6.6	8.52	8.52	1.55
0.381	6.9	9.52	9.53	1.62
0.441	7.7	11.03	11.03	1.82
0.502	8.0	12.53	12.54	1.87
0.582	8.1	14.53	14.54	1.87

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client	CH2M HILL	Boring No.	NA
Client Reference	CAMP LEJUENE	Depth (ft.)	NA
Project No.	2005-522-01	Sample No.	1%B
Lab ID	2005-522-01-01	Visual	BROWN SANDY CLAY



Tested By MPS

Date 4/18/2005 Approved By

Date



**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 2%A  
Visual BROWN SANDY CLAY

**INITIAL SAMPLE DIMENSIONS**

Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in. <sup>2</sup> )	3.142

**WATER CONTENT**

Tare No.	G-1
Wt. Tare + WS.(gms)	41.27
Wt. Tare + DS.(gms)	37.15
Wt. of Tare(gms)	22.08
% Moisture	27.34

**UNIT WEIGHT**

Wt. Tube & WS.(gms.)	383.8	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.86
Wt. Of WS.(gms.)	383.84	Unit Wet Wt.(pcf.)	116.31
Diameter (in.)	2.00	Moisture Content, %	27.34
Length (in.)	4.00	Unit Dry Wt.(pcf.)	91.34
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	1.4	0.00	0.00	0.00
0.002	3.8	0.05	0.04	0.77
0.004	3.8	0.10	0.10	0.78
0.008	4.8	0.20	0.19	1.10
0.014	5.8	0.35	0.35	1.41
0.022	5.9	0.55	0.55	1.45
0.032	6.7	0.80	0.81	1.70
0.040	7.3	1.02	1.01	1.88
0.052	8.3	1.30	1.30	2.20
0.068	9.3	1.70	1.70	2.48
0.084	10.6	2.10	2.10	2.89
0.108	12.3	2.70	2.71	3.38
0.124	13.2	3.10	3.11	3.67
0.156	15.5	3.92	3.90	4.34
0.188	17.6	4.72	4.71	4.92
0.220	19.9	5.52	5.51	5.57
0.241	20.7	6.02	6.01	5.78
0.281	23.5	7.02	7.01	6.56
0.301	24.2	7.52	7.51	6.72
0.341	25.6	8.52	8.52	7.06
0.381	21.3	9.52	9.52	5.75
0.441	10.2	11.02	11.02	2.51
0.501	10.8	12.52	12.52	2.64
0.581	9.7	14.52	14.52	2.28

Tested By MPS

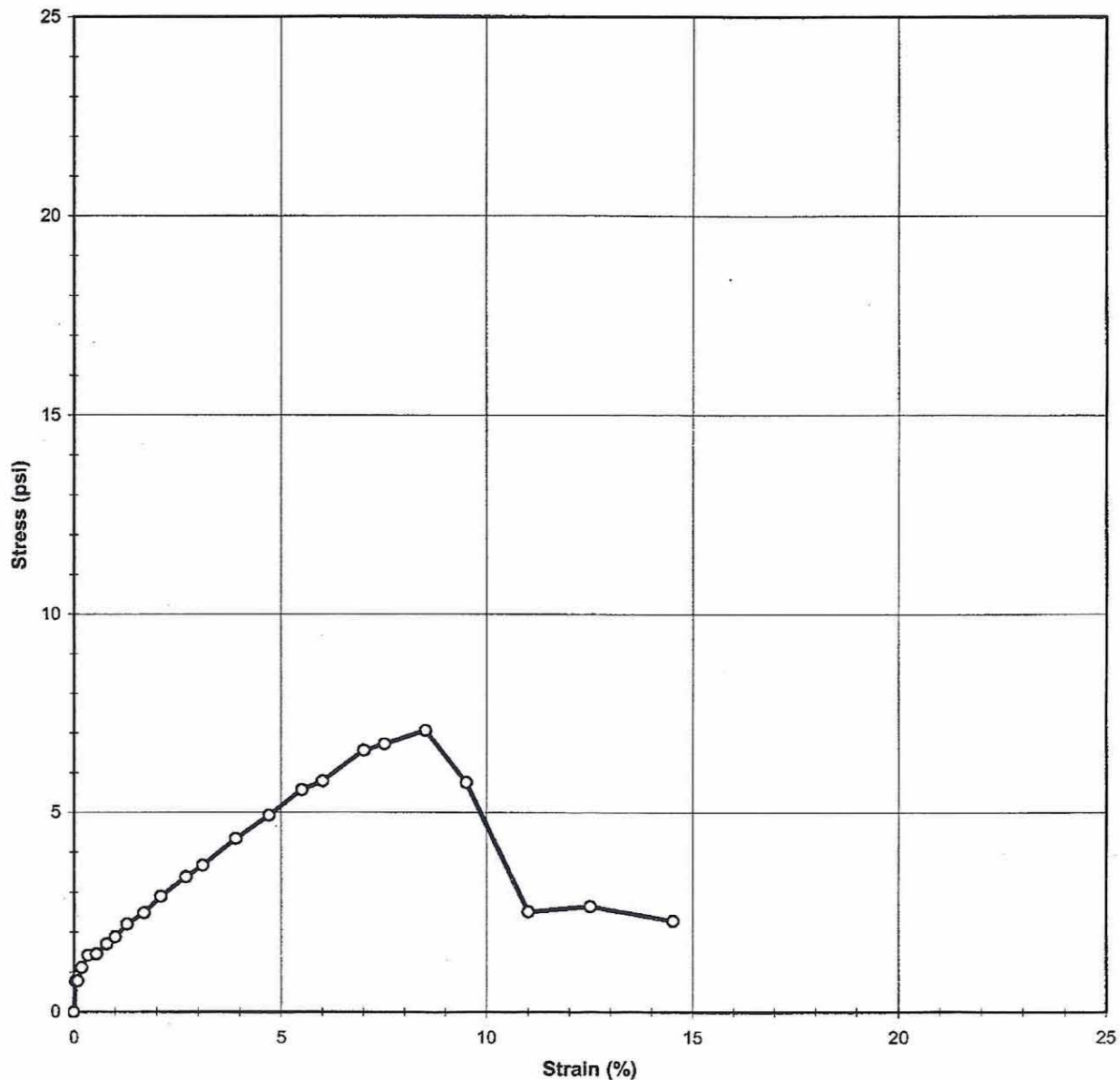
Date 4/18/2005 Input Checked By KAN

Date 4-20-05

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 2%A  
Visual BROWN SANDY CLAY



Tested By MPS

Date 4/18/2005 Approved By

Date

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 2%B  
Visual BROWN SANDY CLAY

INITIAL SAMPLE DIMENSIONS			
Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in.^2)	3.142

WATER CONTENT	
Tare No.	O-1
Wt. Tare + WS.(gms)	43.23
Wt. Tare + DS.(gms)	38.57
Wt. of Tare(gms)	22.00
% Moisture	28.12

UNIT WEIGHT			
Wt. Tube & WS.(gms.)	384.7	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.87
Wt. Of WS.(gms.)	384.7	Unit Wet Wt.(pcf.)	116.57
Diameter (in.)	2.00	Moisture Content, %	28.12
Length (in.)	4.00	Unit Dry Wt.(pcf.)	90.98
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	2.1	0.00	0.00	0.00
0.002	2.5	0.05	0.05	0.14
0.004	2.9	0.10	0.10	0.26
0.008	4.4	0.20	0.19	0.73
0.014	5.1	0.35	0.35	0.96
0.022	5.8	0.55	0.54	1.18
0.032	6.7	0.80	0.80	1.45
0.040	7.8	1.00	1.00	1.80
0.052	8.6	1.30	1.30	2.03
0.068	9.6	1.70	1.69	2.34
0.084	10.3	2.10	2.09	2.56
0.108	12.6	2.70	2.70	3.25
0.124	13.3	3.10	3.09	3.44
0.156	15.6	3.90	3.90	4.14
0.188	17.7	4.70	4.70	4.72
0.204	18.4	5.10	5.10	4.94
0.224	19.6	5.62	5.60	5.27
0.264	22.2	6.62	6.60	5.96
0.284	23.3	7.12	7.11	6.26
0.324	25.8	8.12	8.11	6.93
0.364	27.1	9.12	9.10	7.25
0.424	23.9	10.62	10.60	6.20
0.484	14.8	12.12	12.11	3.56
0.564	11.5	14.12	14.11	2.57

Tested By MPS

Date 4/18/2005 Input Checked By KAW

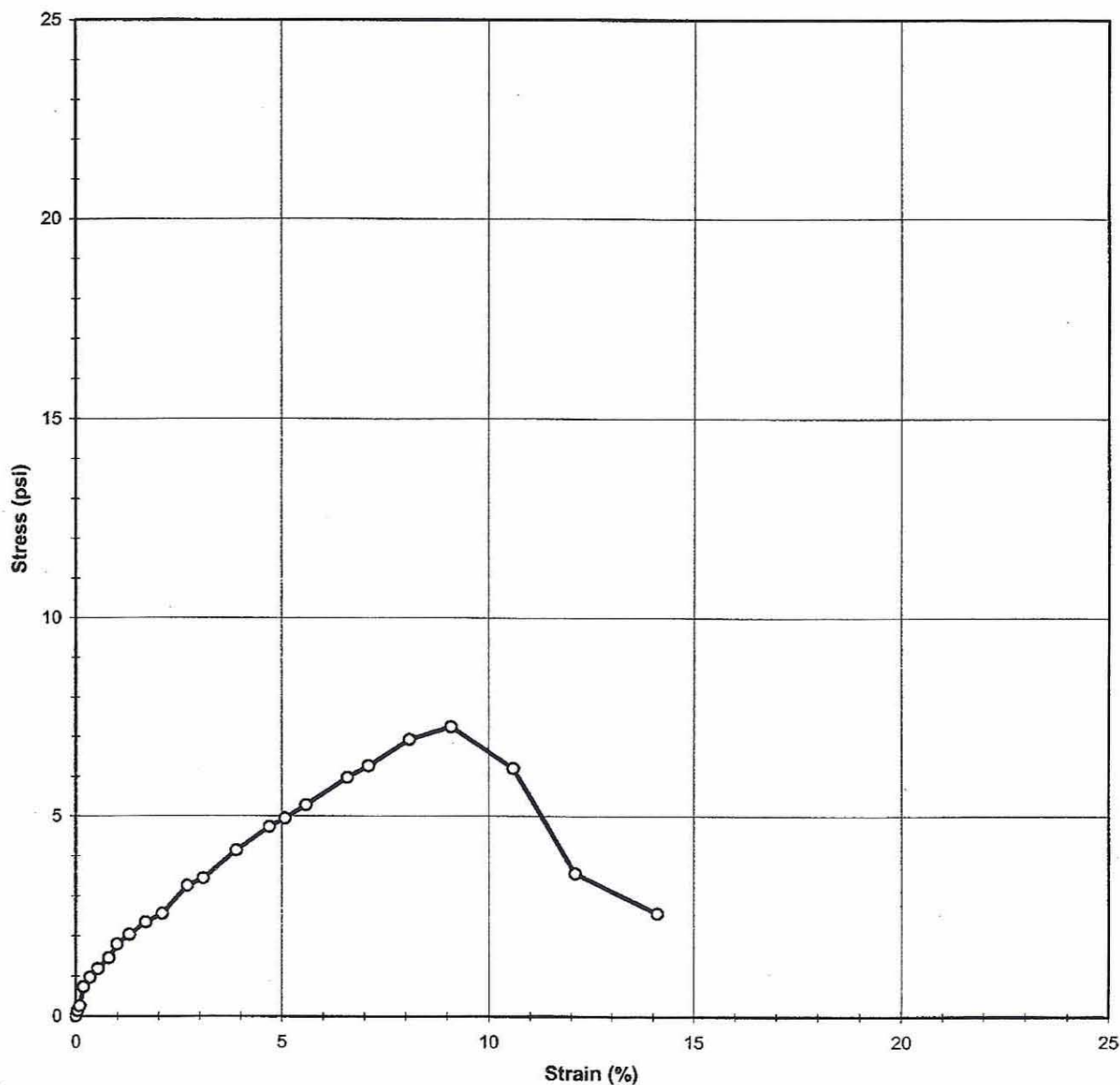
Date 4-20-05



**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 2%B  
Visual BROWN SANDY CLAY



Tested By MPS Date 4/18/2005 Approved By Date  
page 2 of 2 DCN: CT-S30 Date: 1/27/03 Revision: 3 \Lab1\CV2005 Projects\2005-522 CH2M HILL\2005-522-01-01 2%B UC.xls\Sheet1

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 4%A  
Visual BROWN SANDY CLAY

INITIAL SAMPLE DIMENSIONS			
Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in. <sup>2</sup> )	3.142

WATER CONTENT	
Tare No.	B-1
Wt. Tare + WS.(gms)	45.82
Wt. Tare + DS.(gms)	40.62
Wt. of Tare(gms)	22.04
% Moisture	27.99

UNIT WEIGHT			
Wt. Tube & WS.(gms.)	386.2	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.88
Wt. Of WS.(gms.)	386.17	Unit Wet Wt.(pcf.)	117.02
Diameter (in.)	2.00	Moisture Content, %	27.99
Length (in.)	4.00	Unit Dry Wt.(pcf.)	91.43
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	1.2	0.00	0.00	0.00
0.002	2.3	0.05	0.05	0.35
0.004	8.2	0.10	0.10	2.22
0.008	19.4	0.20	0.19	5.79
0.014	45.6	0.35	0.34	14.08
0.022	85.0	0.55	0.55	26.51
0.032	107.7	0.80	0.80	33.61
0.048	120.3	1.20	1.19	37.44
0.064	130.7	1.62	1.60	40.56
0.080	138.5	2.02	2.00	42.82
0.096	141.3	2.42	2.40	43.51
0.120	112.7	3.02	3.00	34.40
0.136	86.7	3.42	3.40	26.28
0.168	21.4	4.22	4.21	6.15
0.200	20.4	5.02	5.00	5.80
0.240	19.7	6.02	6.00	5.52
0.260	14.5	6.52	6.51	3.96
0.300	13.0	7.52	7.51	3.46
0.320	12.4	8.02	8.01	3.26
0.361	13.0	9.02	9.01	3.40
0.401	11.1	10.02	10.01	2.81
0.460	11.7	11.52	11.51	2.96
0.521	11.1	13.02	13.02	2.73
0.600	11.8	15.02	15.01	2.87

Tested By MPS

Date 4/18/2005 Input Checked By KAW

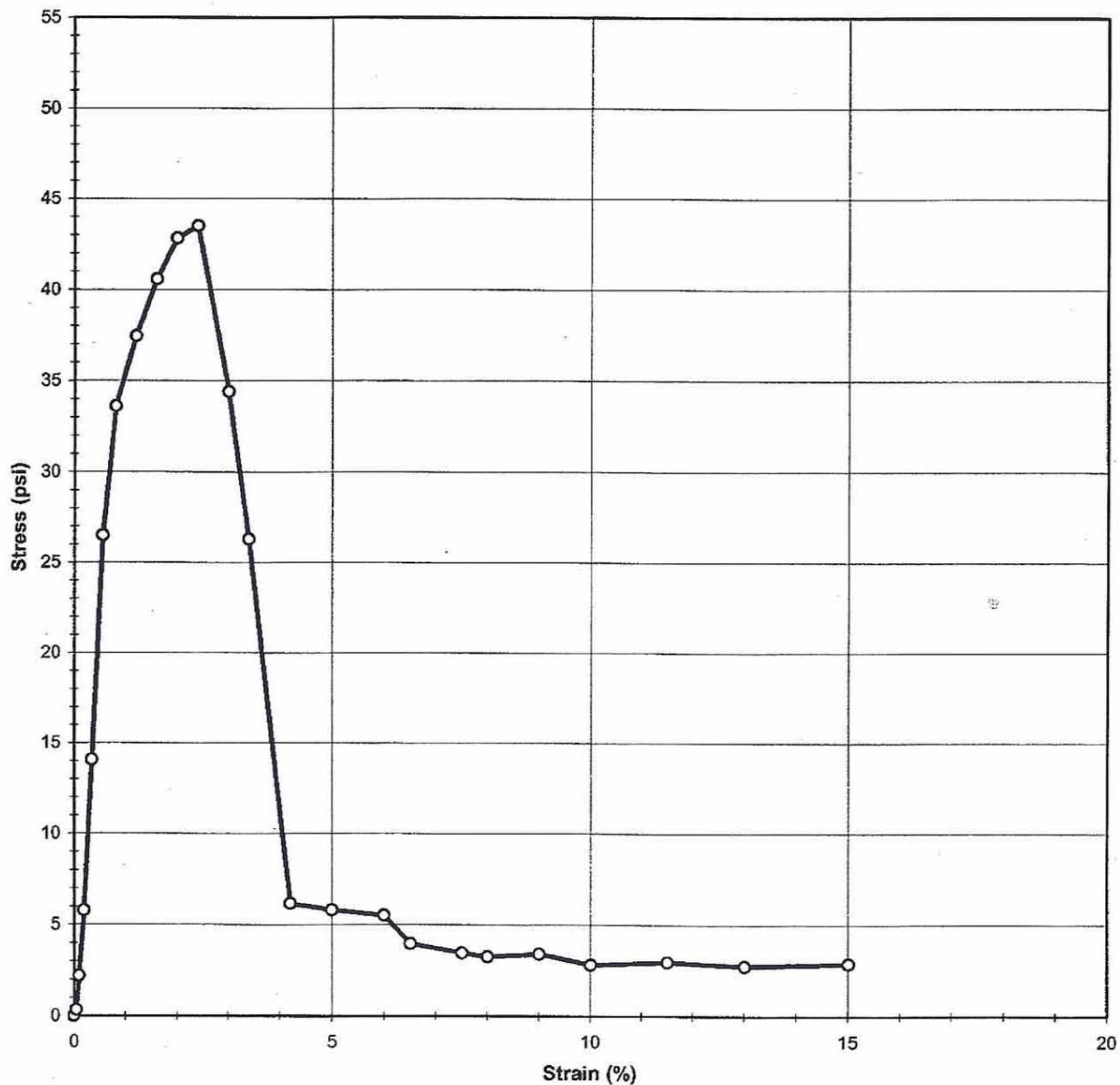
Date 4-20-05

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client  
Client Reference  
Project No.  
Lab ID

CH2M HILL  
CAMP LEJUENE  
2005-522-01  
2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 4%A  
Visual BROWN SANDY CLAY



Tested By MPS

Date 4/18/2005 Approved By

Date



**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 4%B  
Visual BROWN SANDY CLAY

**INITIAL SAMPLE DIMENSIONS**

Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in. <sup>2</sup> )	3.142

**WATER CONTENT**

Tare No.	H-1
Wt. Tare + WS.(gms)	43.59
Wt. Tare + DS.(gms)	38.81
Wt. of Tare(gms)	21.92
% Moisture	28.30

**UNIT WEIGHT**

Wt. Tube & WS.(gms.)	385.2	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.87
Wt. Of WS.(gms.)	385.18	Unit Wet Wt.(pcf.)	116.72
Diameter (in.)	2.00	Moisture Content, %	28.30
Length (in.)	4.00	Unit Dry Wt.(pcf.)	90.97
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	1.8	0.00	0.00	0.00
0.002	9.5	0.05	0.05	2.47
0.004	14.4	0.10	0.10	4.03
0.008	27.7	0.20	0.19	8.22
0.014	48.3	0.35	0.34	14.74
0.022	69.3	0.55	0.55	21.36
0.032	88.9	0.80	0.80	27.50
0.040	99.1	1.00	1.00	30.67
0.052	108.7	1.30	1.30	33.58
0.068	118.5	1.70	1.69	36.54
0.084	126.5	2.10	2.09	38.87
0.108	126.3	2.70	2.70	38.58
0.124	110.4	3.10	3.10	33.50
0.156	20.3	3.90	3.90	5.66
0.188	19.6	4.72	4.70	5.41
0.220	19.1	5.52	5.51	5.21
0.240	19.1	6.02	6.01	5.18
0.280	21.0	7.02	7.00	5.70
0.300	20.9	7.52	7.50	5.63
0.340	18.9	8.52	8.51	4.99
0.381	23.5	9.52	9.52	6.27
0.440	11.5	11.02	11.01	2.77
0.501	12.1	12.52	12.52	2.87
0.581	13.3	14.52	14.51	3.14

Tested By MPS

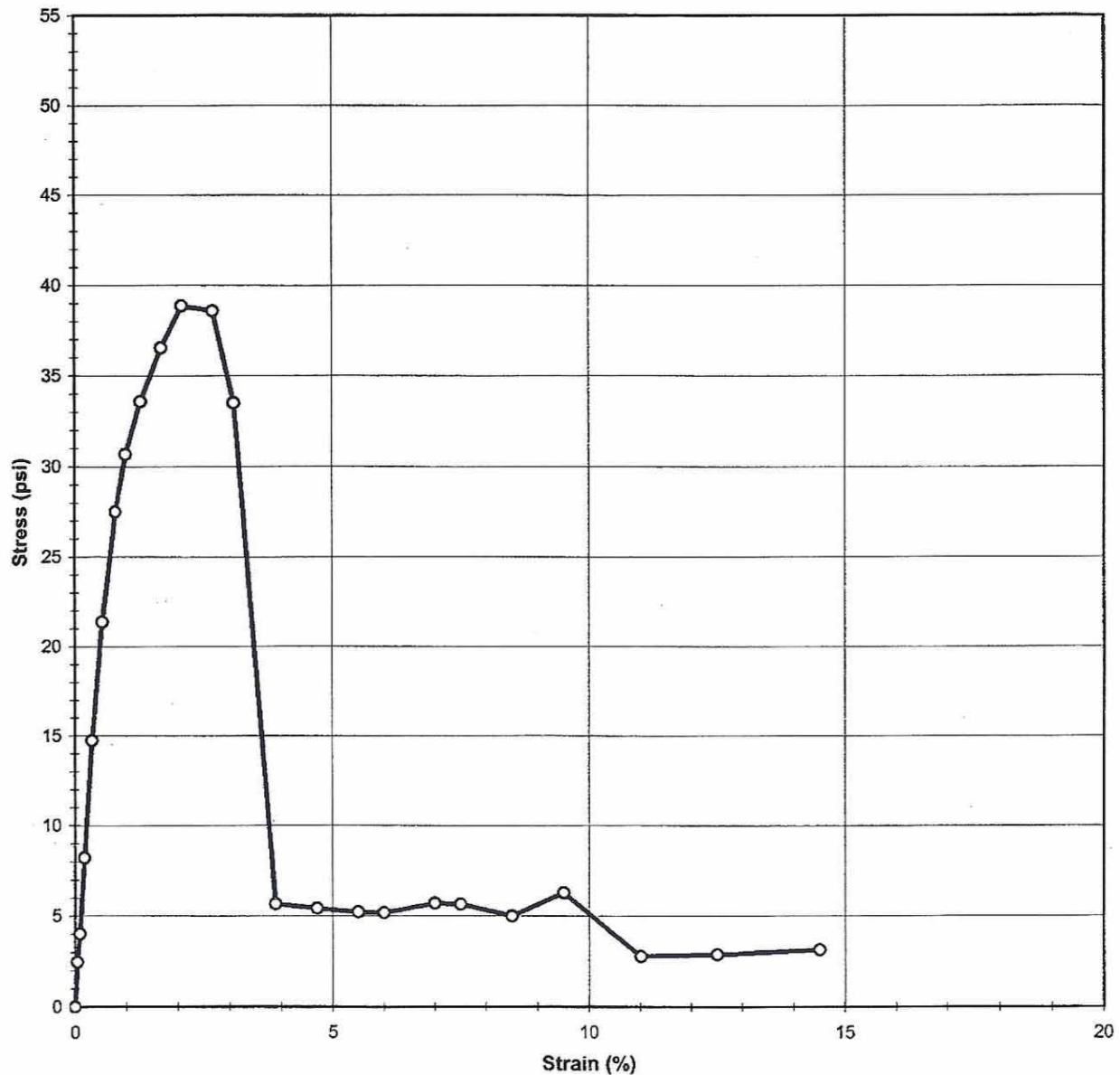
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Date 4-20-05

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 4%B  
Visual BROWN SANDY CLAY



**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 1%PC 2%FA B  
Visual BROWN SANDY CLAY

INITIAL SAMPLE DIMENSIONS			
Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in.^2)	3.142

WATER CONTENT	
Tare No.	U-1
Wt. Tare + WS.(gms)	78.33
Wt. Tare + DS.(gms)	65.54
Wt. of Tare(gms)	21.96
% Moisture	29.35

UNIT WEIGHT			
Wt. Tube & WS.(gms.)	382.5	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.86
Wt. Of WS.(gms.)	382.49	Unit Wet Wt.(pcf.)	115.90
Diameter (in.)	2.00	Moisture Content, %	29.35
Length (in.)	4.00	Unit Dry Wt.(pcf.)	89.61
Length (cm.)	10.16		

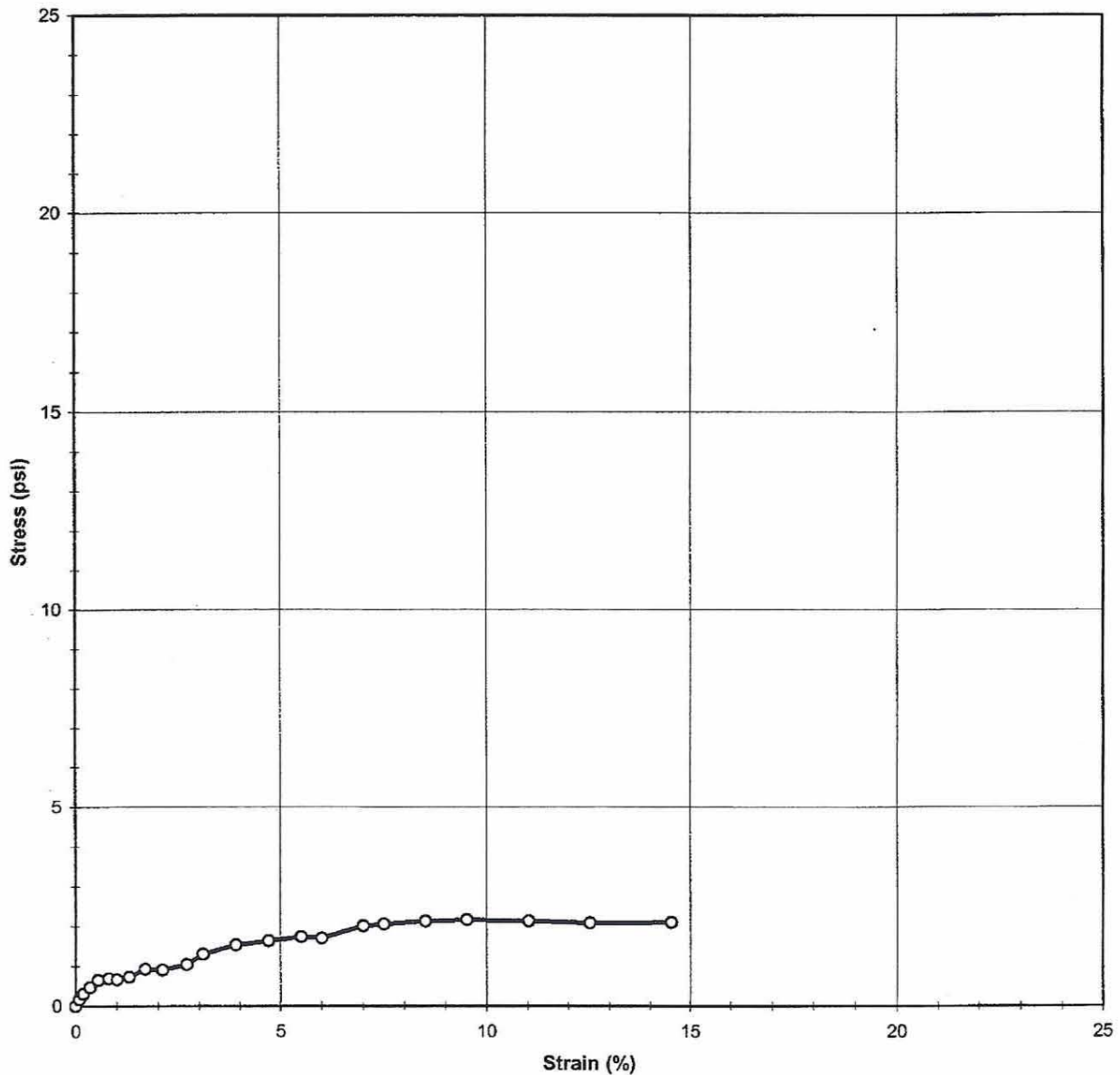
DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	1.5	0.00	0.00	0.00
0.002	1.1	0.05	0.04	-0.11
0.004	2.0	0.10	0.10	0.17
0.008	2.5	0.20	0.19	0.31
0.014	3.0	0.37	0.35	0.47
0.022	3.5	0.57	0.55	0.65
0.032	3.7	0.82	0.80	0.69
0.040	3.6	1.02	1.01	0.66
0.052	3.8	1.32	1.30	0.73
0.068	4.4	1.72	1.70	0.93
0.084	4.4	2.12	2.11	0.90
0.108	4.8	2.72	2.71	1.04
0.124	5.7	3.12	3.10	1.30
0.156	6.5	3.92	3.90	1.53
0.188	6.9	4.72	4.71	1.64
0.221	7.2	5.52	5.51	1.73
0.240	7.2	6.03	6.01	1.70
0.281	8.3	7.03	7.02	2.01
0.301	8.5	7.53	7.52	2.06
0.341	8.8	8.53	8.53	2.13
0.381	9.0	9.53	9.53	2.16
0.441	9.0	11.05	11.03	2.13
0.501	9.0	12.55	12.53	2.08
0.581	9.2	14.55	14.53	2.09



**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 1%PC 2%FA B  
Visual BROWN SANDY CLAY



Tested By MPS Date 04/26/05 Approved By JDR Date 4/29/05  
page 2 of 2 DCN: CT-S30 Date: 1/27/03 Revision: 3 C:\2005 Projects\2005-522 CH2M HILL\2005-522-01-01 1%pc 2%fa B UC.xls\Sheet1

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)



Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 1%PC 2%FA A  
Visual BROWN SANDY CLAY

**INITIAL SAMPLE DIMENSIONS**

Length 1(in)	4.000	Top Dia. (in)	2.000
Length 2(in)	4.000	Mid. Dia. (in)	2.000
Length 3(in)	4.000	Bot. Dia. (in)	2.000
Avg.Length(in)	4.000	Area (in. <sup>2</sup> )	3.142

**WATER CONTENT**

Tare No.	M
Wt. Tare + WS.(gms)	74.78
Wt. Tare + DS.(gms)	61.23
Wt. of Tare(gms)	15.13
% Moisture	29.39

**UNIT WEIGHT**

Wt. Tube & WS.(gms.)	388.3	Sample Volume(cc.)	205.9
Wt. Of Tube(gms.)	0.0	Unit Wet Wt.(gms/cc)	1.89
Wt. Of WS.(gms.)	388.25	Unit Wet Wt.(pcf.)	117.65
Diameter (in.)	2.00	Moisture Content, %	29.39
Length (in.)	4.00	Unit Dry Wt.(pcf.)	90.92
Length (cm.)	10.16		

DEFORMATION (in)	LOAD (lbs)	ELAPSED TIME (min.)	STRAIN (%)	STRESS (psi)
0.000	0.7	0.00	0.00	0.00
0.002	0.9	0.05	0.04	0.07
0.004	0.8	0.10	0.10	0.02
0.008	1.0	0.20	0.20	0.11
0.014	1.5	0.35	0.35	0.27
0.022	1.1	0.55	0.55	0.14
0.032	1.4	0.80	0.81	0.24
0.040	1.8	1.00	1.01	0.34
0.052	1.9	1.30	1.30	0.37
0.068	2.3	1.70	1.70	0.51
0.084	2.1	2.10	2.10	0.45
0.108	2.9	2.70	2.71	0.69
0.124	3.4	3.10	3.10	0.82
0.156	4.0	3.90	3.91	1.02
0.188	4.5	4.72	4.71	1.14
0.221	5.0	5.52	5.51	1.31
0.240	4.8	6.02	6.01	1.23
0.281	6.0	7.02	7.02	1.56
0.301	6.0	7.52	7.52	1.56
0.341	6.1	8.52	8.52	1.59
0.381	6.7	9.52	9.52	1.74
0.441	7.0	11.02	11.02	1.78
0.501	7.2	12.53	12.53	1.80
0.581	7.4	14.53	14.53	1.82

Tested By MPS

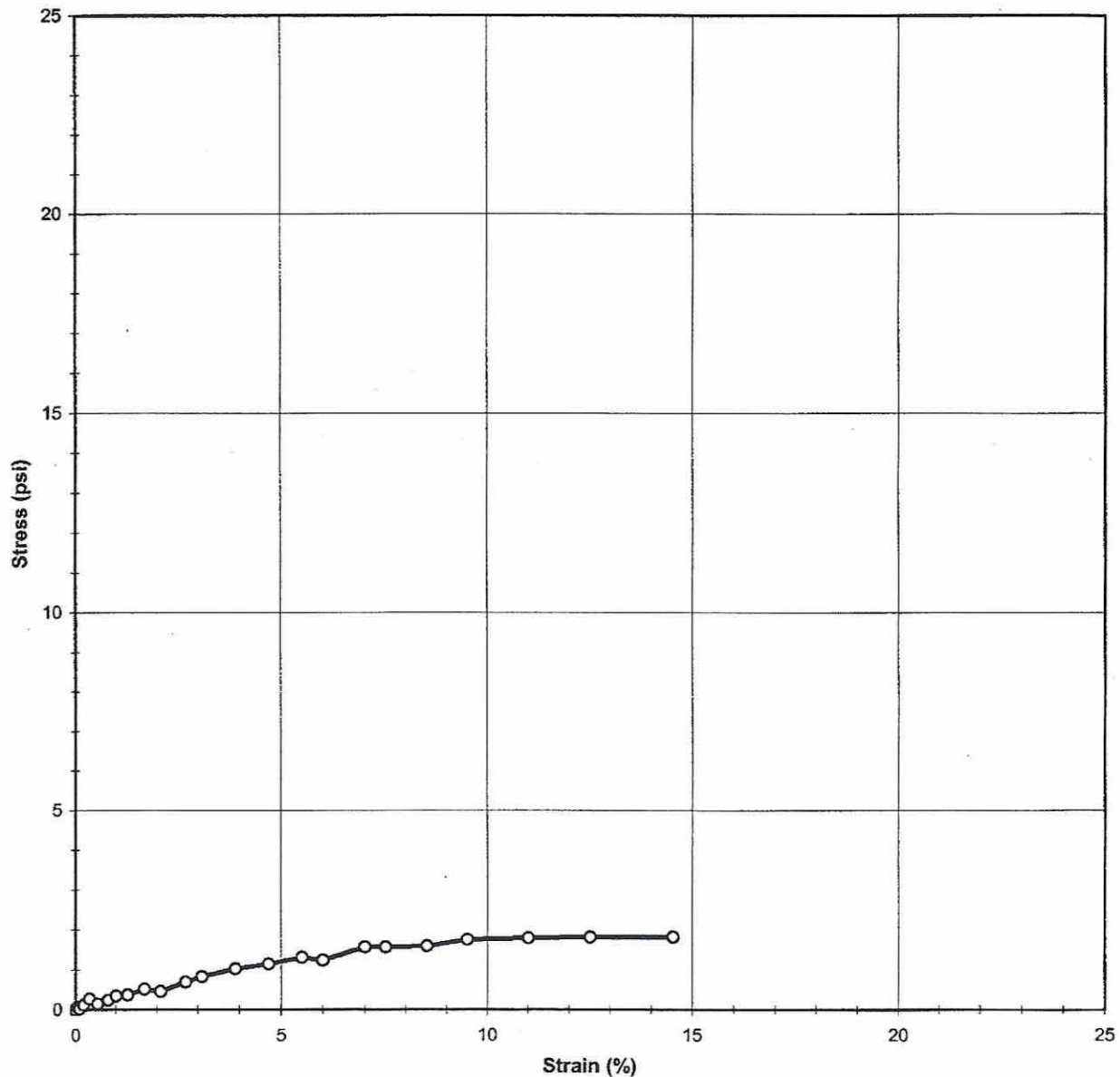
Date 4/26/2005 Input Checked By JDR

Date 4/29/05

**UNCONFINED COMPRESSIVE STRENGTH**  
ASTM D2166-00 (SOP S-30)

Client CH2M HILL  
Client Reference CAMP LEJUENE  
Project No. 2005-522-01  
Lab ID 2005-522-01-01

Boring No. NA  
Depth (ft.) NA  
Sample No. 1%PC 2%FA A  
Visual BROWN SANDY CLAY



Tested By MPS

Date 4/26/2005 Approved By

JDR

Date 4/29/05



# Appendix E

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## Stabilization Quality Control Results

**Cone Index (Qc) Penetrometer Readings**  
**May 23, 2005**

Depth	0 ft to 1 ft	1 ft to 2 ft	2 ft to 3 ft	Average
Grid	Qc1 (kg/cm2)	Qc2 (kg/cm2)	Qc3 (kg/cm2)	
1	13.00	8.33	8.00	9.8
2	10.67	13.33	10.67	11.6
3	18.67	12.00	17.00	15.9
4	13.67	16.33	13.67	14.6
5	5.00	6.00	6.33	5.8
6	9.67	9.00	13.67	10.8
7	8.00	7.67	14.67	10.1
8	17.33	17.67	19.67	18.2
9	16.33	10.00	20.67	15.7
9'	16.33	3.00	4.67	8.0
10	16.33	17.33	16.33	16.7
11	20.67	6.33	20.33	15.8
12	24.67	15.00	16.00	18.6
13	17.33	20.33	18.00	18.6
14	14.33	12.67	6.67	11.2
15	23.33	27.33	19.33	23.3
16	28.33	27.67	19.33	25.1
17	22.00	17.67	16.67	18.8
18	20.00	35.00	20.33	25.1
18'	22.33	21.33	13.00	18.9
19	9.67	9.67	5.67	8.3
20	14.33	12.00	17.67	14.7
21	13.67	14.67	13.33	13.9
22	5.33	15.00	19.33	13.2
23	10.33	14.67	10.67	11.9
24	12.67	8.33	9.67	10.2
25	17.67	23.33	19.67	20.2
26	12.00	14.33	11.00	12.4
27	12.67	13.67	13.67	13.3
27'	10.67	28.67	29.00	22.8
29	7.00	10.67	17.00	11.6
30	18.33	23.00	26.00	22.4
31	23.33	24.67	32.67	26.9

## Treatment Unit ID & Sequence

	15 ft	15 ft	15 ft		
12 ft	19	1	10	grid 1: pumping; grid 10: air bubbles	
12 ft	20	2	11		
12 ft	21	3	12		
12 ft	22	4	13		
12 ft	23	5	14		
12 ft	24	6	15		
12 ft	28	25	7	16	grid 25: pumping
12 ft	29	26	8	17	grid 8/26; pumping
12 ft	30	27	9	18	
12 ft	31	27'	9'	18'	grid 9'; pumping

Grids in blue have  
standing surface water  
5/24/05

15 ft			15 ft	15 ft				Tracks only	1 to 8" rut	3 to 4" rut	10N: 2 to 5" rut 25' long
12 ft	12 ft	19	1	10	12 ft	12 ft	19: 6 inch rut, pumping	1: 3 to 12" rut 4 ft long	10: 2 to 3" rut		
	12 ft	20	2	11		12 ft	20: 1 to 5" rut	2: 0 to 3" rut	11: No tracks	11N: 2 to 4" rut 15" long	
	12 ft	21	3	12		12 ft	21: 2 to 4" rut	3: tracks only	12: 2 to 6" rut, 2' long	12N: 1" rut 15 ft long	
	12 ft	22	4	13		12 ft	22: 2 to 6" rut	4: 2 to 3" rut	13: 1" rut		
	12 ft	23	5	14		12 ft	23: 2 to 6" rut	5: 3 to 6" rut	14: 2 to 4" rut; pumping	14N: 1" elastic movement/pumping	
	12 ft	24	6	15		12 ft	24: 1 to 2" rut	6: 0 to 6" rut; pumping	15: tracks only	tracks only	
28		25	7	16	12 ft	28: 1 to 4" rut	25: 1 to 3" rut	7: track marks only; 1/4" cracks	16: tracks only		
29		26	8	17	12 ft	29: 2 to 12" rut	26: 4 to 8" rut, pumping 1 - 2 "	8: 2 to 4" rut; pumping; 1/4" cracks	17: tracks only; 1' dia soft spot		
30		27	9	18	12 ft	30: 1/2" rut	27: 1 to 6" rut, pumping	9: 2 to 5" ruts	18: 3" rut; 2' long	18N: 2 to 3" rut	
31		27'	9'	18'	12 ft	31: No tracks	27': 12" rut	9': 2 to 10" rut - 9' long; 1/4" cracks	18': 2 to 5" rut; 8f long		

Grids in yellow have at least one Cone Index average  
below 15 kg/cm<sup>2</sup>

## Proof Rollings Results

	Tracks only	1 to 8" rut	3 to 4" rut	
12 ft	19: 6 inch rut, pumping	1: 3 to 12" rut 4 ft long	10: 2 to 3" rut	10N: 2 to 5" rut 25' long
12 ft	20: 1 to 5" rut	2: 0 to 3" rut	11: No tracks	11N: 2 to 4" rut 15" long
12 ft	21: 2 to 4" rut	3: tracks only	12: 2 to 6" rut, 2' long	12N: 1" rut 15 ft long
12 ft	22: 2 to 6" rut	4: 2 to 3" rut	13: 1" rut	
12 ft	23: 2 to 6" rut	5: 3 to 6" rut	14: 2 to 4" rut; pumping	14N: 1" elastic movement/pumping
12 ft	24: 1 to 2" rut	6: 0 to 6" rut; pumping	15: tracks only	tracks only
12 ft	28: 1 to 4" rut	25: 1 to 3" rut	7: track marks only; 1/4" cracks	16: tracks only
12 ft	29: 2 to 12" rut	26: 4 to 8" rut, pumping 1 - 2"	8: 2 to 4" rut; pumping; 1/4" cracks	17: tracks only; 1' dia soft spot
12 ft	30: 1/2" rut	27: 1 to 6" rut, pumping	9: 2 to 5" ruts	18: 3" rut; 2' long
12 ft	31: No tracks	27': 12" rut	9': 2 to 10" rut - 9' long; 1/4" cracks	18N: 2 to 3" rut
12 ft			18': 2 to 5" rut; 8f long	



# **Appendix F**

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## **As-Built Parking Lot Plans**

# Photo Log

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Former Building 25 Concrete Slab – side view



Removal of Concrete Slab of Former Building 25





Site Preparation for Mixing



150-ton Manitowac 4000 W Series Crane



10 ft. Diameter Mixing Auger





Kelley Bar



Mixing Tanks





ZVI Loading into Mixing Tank



Mixing Hood with Kelley Bar, Mixing Auger, and Off-Gas line to Air Treatment System





Carbon Filter for Off-Gas Treatment



Shallow Soil Mixing



Shallow Soil Mixing



Iron-Bentonite Slurry Sampling





Treatment Area after Mixing



Treatment Area Stabilization





Treatment Area after Stabilization



Treatment Area after Stabilizaiton





Post Mix - Soil Boring Location # 100. Depth = 20 ft.



Post Mix - Soil Boring Location # 101. Depth = 17.5-18.5ft.





Post Mix- Soil Boring Location # 101. Depth = 18-20 ft



Post Mix- Soil Boring Location # 102. Depth = 18 ft.



Post Mix- Soil Boring Location # 109. Depth = 18 ft.